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EVALUATION OF A SIMPLIFIED RIDGE MODELLING METHOD

VOLUME I - MAIN REPORT

TP 10202E

Prepared for:

Transportation Development Centre
Policy and Coordination Group
Transport Canada

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DISCLAIMER:

The contents of this report reflect the views of Fleet Technology Limited and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la Table des matières.

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16. Abstract

A project has been undertaken to evaluate, and develop a database for, a simplified method for modelling ridges in the ice model basin. This method is aimed at simulating the incremental penetration energy, which is defined as the additional energy required by the ship to penetrate the ridge over that amount which would have been expended had there not been a ridge in the ice. Efforts were made to model this incremental penetration energy by conducting tests with separate sheets of level ice and rubble ice, only. The penetration phase of these tests (in which the model entered the ice edge) was analyzed to predict the resistance and energy for a ridge of limited width.

Tests were conducted at FTL's laboratory in Kanata using refrigerated, EGAD-doped, model ice. Tests were conducted with a 19.1:1 scale model of the USCGC POLAR STAR and a 22.5:1 scale model of the MV KIGORIAK.

A simple computer program was written to predict icebreaker resistance and performance in ridges up to the vessel's limiting ridge capability. The peak resistance of the POLAR STAR compares within 5% of the field ramming data for this ship after corrections are applied to the model test and field data. The computer program was run for a number of cases to predict the size of the limiting ridge for the POLAR STAR and the MV KIGORIAK.

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16. Résumé

La recherche dont il est rendu compte concerne l'évaluation d'une méthode simplifiée de modélisation des crêtes de pression, et la mise en place de la base de données correspondante. Le modèle ainsi obtenu permet de calculer le surplus d'énergie (incrément) que doit développer un brise-glace chargeant une crête de pression, par rapport à l'énergie dépensée si cette crête n'existait pas. Des essais sur maquettes ont été menés dans des glaces uniformes et des glaces fragmentées, afin de parvenir à des prévisions sur la valeur d'énergie de l'incrément requis. L'analyse de la portion de ces essais durant laquelle la proue de la maquette pénètre dans la glace a permis de dégager des prévisions sur les valeurs de résistance et d'énergie à l'égard d'une crête de largeur finie.

Les essais menés dans le bassin des glaces de Fleet Technology Ltd. à Kanata ont mis en oeuvre une glace modèle réfrigérée et dopée, une maquette 1:19,1 du brise-glace POLAR STAR et une maquette 1:22,5 du KIGORIAK.

Un programme informatique simple a été rédigé, permettant de prévoir les valeurs de résistance à l'avancement et les distances de franchissement de différentes crêtes, y compris celles que le navire est incapable de franchir. Les prévisions ainsi obtenues sur l'aptitude du POLAR STAR se comparent aux données réelles le concernant, dans une marge de 5 p. 100. Ce programme a servi à définir les limites de l'aptitude du POLAR STAR et du KIGORIAK à franchir des crêtes dans des conditions variées.

17. Mots clés
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EXECUTIVE SUMMARY

This project is Phase II of a two phase study performed to establish a method to evaluate icebreaking ship performance in first year ice ridges. The first phase was carried out to evaluate the accuracy of current ridge modelling techniques and investigate preferred techniques for modelling ridges in the ice basin.

The approach taken in Phase I was to duplicate, at model scale, two ridge ramming tests obtained from the USCGC POLAR STAR icebreaker. Two approaches were evaluated; a "combined" modelling and a "separate" modelling of the consolidated and unconsolidated components of ridges. The latter approach was much simpler to perform and was the focus of the Phase II study, the subject of this report.

The work in Phase II consisted of establishing a method to test a ship through a first year ice ridge without stopping, termed here, "single-pass" ramming. The two ridge ramming tests obtained from the USCGC POLAR STAR icebreaker and used in Phase I were used in this Phase as a full scale reference.

The general approach was based on viewing the field ridge as a combination of the level ice and some additional ice. The additional ice is a combination of both level ice and broken ice where the consolidated part of the ridge is represented with an equivalent level ice thickness and the unconsolidated ridge keel is represented with an equivalent broken ice thickness.

To predict the penetration energy of this additional ice, standard model tests for two ship models, the POLAR STAR and the KIGORIAK, were performed using level ice sheets and accumulations of broken ice only. These ice features are simple to reproduce in the basin and their properties can be controlled relatively well.

The penetration phase of the ship bow through the ice edge was analyzed to provide data for ridge modelling. This was necessary as ridges are usually limited in width, often being less than one ship length in width. A mean penetration function for the POLAR STAR and the KIGORIAK in level ice and broken ice was obtained. This penetration function was used to predict the resistance versus distance relationship for a ridge of limited width.

The last task was carried out to prepare, exercise and deliver a simple computer-based numerical program which provides graphical output for the preliminary prediction of icebreaker resistance and performance in first year ice ridges up to the vessel's limiting ridge capability. The program, although not ship-specific, was calibrated based on the POLAR CLASS icebreakers for which full scale and model scale data in level ice and in ridges are available. The program can accommodate a range of level ice thicknesses and ridge consolidated and unconsolidated depths. It provides a prediction of the resistance and velocity versus distance curves for single-pass ramming events.

The program was exercised for both the POLAR STAR and the KIGORIAK with respect to ridge ramming events 17 and 18. It predicted the maximum resistance for the POLAR STAR within 5% of the "corrected" field data. This comparison was not possible for the KIGORIAK as full scale ridge ramming data are not publicly available for this ship. The program was also exercised to define the performance of the POLAR STAR and the KIGORIAK for a limiting ridge for a number of surrounding level ice thicknesses and ridge depths.

SOMMAIRE

Ce rapport concerne la phase II d'une étude en deux phases visant à mettre au point une méthode permettant d'évaluer l'aptitude d'un brise–glace à franchir des crêtes de pression formées de glace de première année. La phase précédente avait consisté à évaluer la justesse des techniques de modélisation connues et à approfondir les techniques à privilégier pour la modélisation de crêtes dans un bassin de glaces.

La phase I avait consisté à reproduire, à l'échelle, deux cas de charge sur des crêtes de pression, à partir des données obtenues à bord du brise–glace POLAR STAR des Etats–Unis. Pour la modélisation, deux approches avaient été envisagées: modélisation combinée et modélisation distincte des éléments consolidés et non consolidés d'une crête de pression. C'est cette dernière méthode beaucoup plus simple qui a été choisie pour devenir l'essentiel de la phase II, objet du présent rapport.

La recherche a consisté à trouver une méthode d'évaluation concernant un navire qui franchit une crête de pression formée de glaces de première année sans s'arrêter, effectuant ce qu'il a été convenu d'appeler une "charge simple". Pour cela, les données obtenues à bord du POLAR STAR au cours de la phase I ont pu être utilisées.

Pour la modélisation, la crête de pression a été considérée comme un ensemble formé de glaces uniformes et de glaces combinées. Ces dernières sont considérées comme constituées de glaces uniformes et de glaces fragmentées, où la portion uniforme (consolidée) de la crête est représentée par une épaisseur équivalente de glace uniforme et la portion fragmentée (non consolidée) par une épaisseur équivalente de glace fragmentée.

Afin de pouvoir calculer l'énergie de pénétration de la glace combinée, des essais standard sur des maquettes de deux navires – le POLAR STAR et le KIGORIAK – ont été menés dans des glaces uniformes et dans des amas de glace fragmentée, conditions glacielles faciles à reproduire en bassin et dont les caractéristiques sont faciles à maîtriser.

La phase de pénétration de la proue dans la crête a été analysée pour obtenir les données nécessaires à la modélisation des crêtes de pression. Ce travail a été nécessaire du fait que les crêtes sont généralement de largeur finie, souvent inférieure à une longueur de navire. Une fonction de la résistance de pénétration moyenne du POLAR STAR et du KIGORIAK dans une glace uniforme et fragmentée a pu être obtenue, laquelle a été utilisée pour établir des courbes de distances de franchissement en fonction de la résistance d'une crête de largeur finie.

La dernière tâche a porté sur la préparation, la mise en oeuvre et la livraison d'un programme de calcul numérique donnant sous forme de graphique les prévisions préliminaires sur les énergies et les distances de franchissement de crêtes de première année, et ce jusqu'à la limite de l'aptitude du navire à effectuer de tels franchissements. Ce programme, bien que non spécifique, a été coté grâce aux données sur les essais en vraie grandeur et sur maquette dans des glaces uniformes et des crêtes menés sur les brise–glace de type POLAR STAR. Ce programme qui permet de faire varier les paramètres d'épaisseur de la glace uniforme et la hauteur des portions de glace consolidées et non consolidées, fournit des prévisions sous forme de courbes des distances de franchissement en fonction de la résistance des crêtes et de l'allure du navire, lors de charges simples.

Ce programme a été mis en oeuvre dans le cas du POLAR STAR et du KIGORIAK, à l'égard des deux cas de charge 17 et 18 et a fourni des prévisions sur l'aptitude maximale du POLAR STAR à franchir des crêtes, prévisions qui se comparent aux données réelles à 5 p. 100 près. Ce programme a également servi à définir les limites de l'aptitude du POLAR STAR et du KIGORIAK à franchir des crêtes dans des conditions variées d'épaisseur de glace uniforme et de hauteur des crêtes.

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1. INTRODUCTION

1.1 Background

The performance of a ship in ridges can greatly affect its ability to operate in an ice environment. This aspect of ship performance is not well understood at present. Recently, a study was undertaken [1][1] to investigate: (a) the accuracy of physical ridge modelling techniques, and, (b) preferred techniques for modelling ridges in the ice basin. That study was focused on the modelling of first year ridges. It attempted to duplicate at model scale, a small number of field ridge transitting tests that were conducted in first year ridges with the USCGC POLAR STAR by [2]. Model tests were conducted at both the Institute of Marine Dynamics and Fleet Technology Limited. Two general ridge modelling approaches were evaluated, as follows:

(a) "Complete" modelling in which the ridges consisted of both consolidated and unconsolidated material. This models the general composition of the field ridge(s).

(b) "Separate" modelling in which the consolidated and unconsolidated portions of the field ridge(s) are separately modelled. Separate penetration tests were conducted and the measured penetration energies were summed numerically for comparison with the field data.

These ridge modelling approaches are shown schematically in Figure 1.1. The latter approach was much simpler to perform. These ridges were easier to produce in the basin and the properties of these ridges could be controlled more accurately. The modelling accuracy of both approaches (which was measured by their ability to predict the measured field penetration energy) was similar. Hence, these results showed that the "separate" ridge modelling approach has clear advantages.

1.2 Objective

Recently, an extension of the "separate" ridge modelling approach has been proposed by the Transportation Development Centre (TDC) that is aimed at further simplification. This project was undertaken with the objective of investigating and evaluating this approach.

1.3 Project Scope and Organization of Report

The project was comprised of the following tasks:

(a) review of "single-pass" ramming and an analysis of the available field data,

(b) model testing,

(c) development of a simple computer model for analyzing and interpreting the model test results and for predicting full scale performance.

The work carried out with respect to item (a) is described in section 2. Sections 3 and 4 describe and discuss the model tests. Section 5 describes the numerical model and presents results. Conclusions and recommendations are provided in Section 6.

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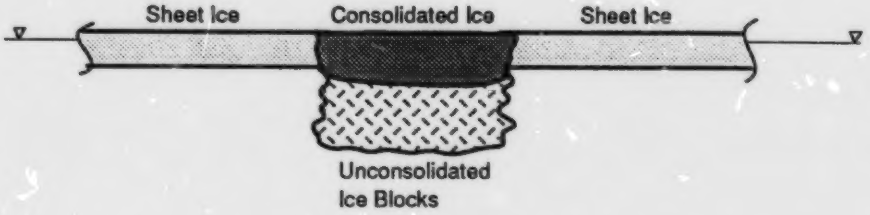
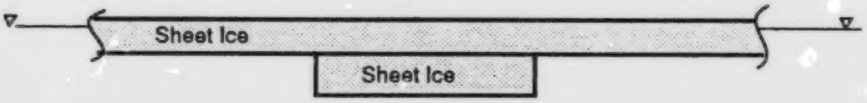
[1] Numbers in brackets designate references listed at the end of the report (Section 7)

“Complete” Modelling:


Sheet Ice
Consolidated Ice
Sheet Ice
Unconsolidated
Ice Blocks

“Separate” Modelling:

Consolidated Portion of Ridge


Sheet Ice
Sheet Ice

+

Unconsolidated Portion of Ridge

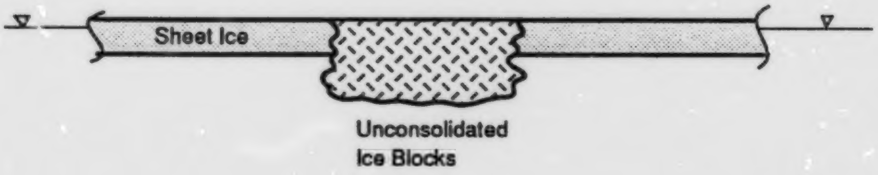

Sheet Ice
Unconsolidated
Ice Blocks

Figure 1.1 Composition of Ridges Tested During Previous Programs

2. RIDGE MODELLING APPROACH AND REVIEW OF AVAILABLE FIELD DATA

2.1 Review of "Single-Pass" Ramming

A review of the ridge transitting process is helpful for understanding the proposed ridge modelling approach. Figure 2.1 illustrates this process for the case where the ship encounters a ridge in a level ice field and it transits the ridge without stopping, which has been termed "single-pass" ramming in this report. The proposed ridge modelling approach is intended to be applicable for "single-pass" ramming.

Figure 2.1 shows how the ship resistance and velocity are expected to vary with distance travelled during "single-pass" ramming. The ship's resistance and velocity prior to contacting the ridge can be expected to be constant, assuming no changes in properties of the level ice (e.g., thickness, strength) and no changes in ship thrust. Upon contacting the ridge, the ship encounters an increase in resistance. This results in a decrease in velocity assuming no changes in ship thrust. Thus, the kinetic energy of the ship is reduced by the ridge. The potential energy may, of course, be increased due to changes in ship attitude. After some travel distance, a ship in the "single-pass" ramming mode will attain the same speed and attitude as the pre-ridge values, assuming no change in ship thrust or differences in properties (e.g., thickness, strength) between the pre-ridge and the post-ridge level ice.

The presence of the ridge causes a temporary increase in the *rate* at which energy must be expended. If the ship's output power is held constant, then its speed (and hence, its kinetic energy) will be reduced by the ridge. Of course, if the ship's speed drops to zero, it will be forced to operate in the ramming mode in order to maintain forward progress. This greatly increases the time required to transit the ridge. It follows, therefore, that, the "limiting" ridge (i.e., the ridge which just causes the ship speed to drop to zero) is of great practical interest.

The size of the "limiting" ridge is dependent on both the ship of interest and the properties of the level ice (e.g., thickness, strength). Clearly, the "limiting" ridge is larger for a more ice-capable ship. The properties of the level ice are also important. The steady-state speed of a ship in thin ice is greater than that for the same ship in thicker ice. Hence, the "limiting" ridge is larger for thin ice as the ship has a larger "reserve" of kinetic energy which can be utilized to maintain forward progress.

The proposed ridge modelling approach is intended to be applicable for the simulation of ridge penetration energies up to that of the "limiting" ridge.

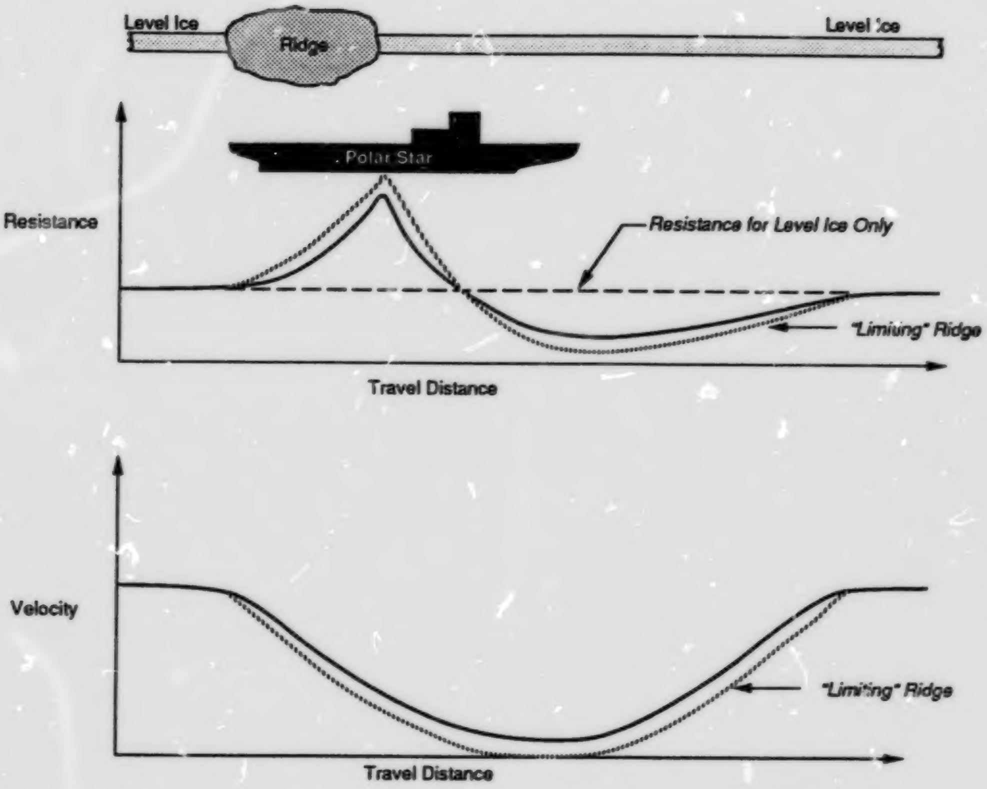

Level Ice
Ridge
Level Ice
Polar Star
Resistance
Resistance for Level Ice Only
"Limiting" Ridge
Travel Distance
Velocity
"Limiting" Ridge
Travel Distance

Figure 2.1 Schematic of Single-Pass Ridge Penetration

2.2 Available Field Data

A review of the available field data was recently carried out [1]. Relatively few tests have been done in sufficient detail to meet the project's data needs which require that both the ice environment and the ship's performance during ramming be documented. However, a number of field tests have been conducted which were considered as potential candidates. These included ridge ramming tests with: (a) the USCGC POLAR STAR in 1982 in the Bering Sea [2]; and (b) the MV KIGORIAK in 1979-80 in the Beaufort Sea [3]; and (c) the MV POLARSTERN in 1984 in the Labrador Sea [4].

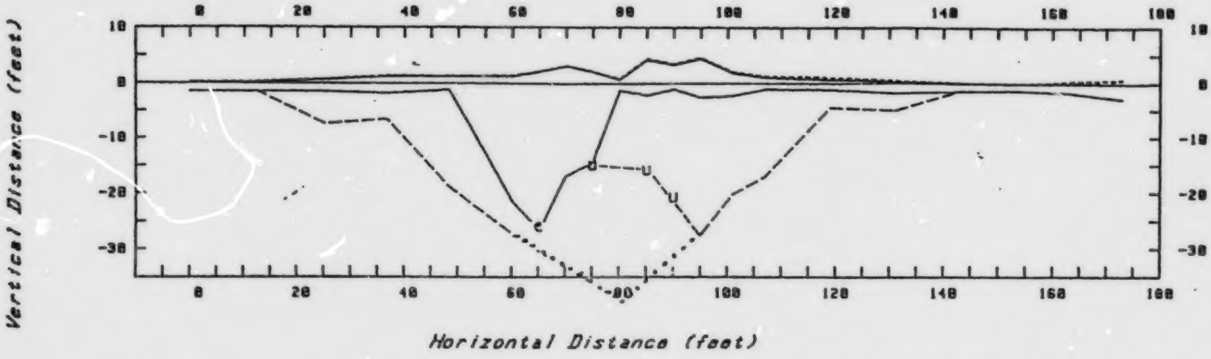
The KIGORIAK was tested in the ramming mode as the ridges were larger than the "limiting" ridge and furthermore, these data are proprietary (to AMOCO Canada Petroleum Ltd). The POLARSTERN tests were conducted in ridges that were totally unconsolidated. These tests were not selected as reference events for this project as the modelling of these ridges is a considerably simpler problem than that of the "POLAR STAR'S ridges" which were partially consolidated.

Hence, it was decided to use the POLAR STAR tests as reference events for this project. This same data set was used as a full scale reference for the previous ridge modelling project [1]. While some anomalies in this data set were noted during that project, this data set is relatively complete in that both the ship's performance and the ridge were documented for the ramming case of interest to this project (i.e., "single-pass" ramming). This allowed a general verification of the proposed ridge modelling approach.

Tests done with ridges 17 and 18 were used as reference events for this project as the ridge profile was documented best for these ridges. Figures 2.2 and 2.3 show the measured ridge profiles for ridges 17 and 18, respectively. Figures 2.4 and 2.5 show the measured force and velocity time histories for ridges 17 and 18, respectively.

These raw data were analyzed to determine the relationship of resistance and velocity, to the distance travelled. Figures 2.6 and 2.7 show these trends for ridges 17 and 18, respectively. The travel distances on these figures have been referenced to the ridge "startpoint". As the field ridge profile data were not referenced to the measured resistance and velocity time histories, it was necessary to select a "startpoint". The ridge "startpoint" was taken as the point at which the ship's resistance began to rise. See figures 2.4 and 2.5.

Figures 2.6 and 2.7 show that the resistance increased quickly when the ship contacted the ridge. The peak resistance was reached after a travel distance of about one ridge width. The resistance then dropped quickly as the ship exitted the ridge. For ridge 17, a travel distance of about two ship lengths was required for the POLAR STAR's velocity and resistance to return to the steady-state "pre-ridge" values. See figure 2.6. The available data record for ridge 18 is much shorter and steady-state travel was not achieved over the period of record. See figure 2.7.



---- Interpolated Profile

PRESSURE RIDGE NO. 17
(First-Year)
Position: Lat. 64° 16.9′ N
Long. 168° 45.1′ W
4/22/82
Floe Drift: Spd. .2 kts.
Course 241° True

Snow Cover: ....
Solid Ice Surfaces: ________________
Total Depth By Drilling: — — — — — —
Sonar Depth: —·—·—·—·—·—·—
C: Consolidated Depth, Ice Below
U: Unconsolidated Depth, Ice Below

PRESSURE RIDGE NO. 17

SUMMARY OF PHYSICAL CHARACTERISTICS

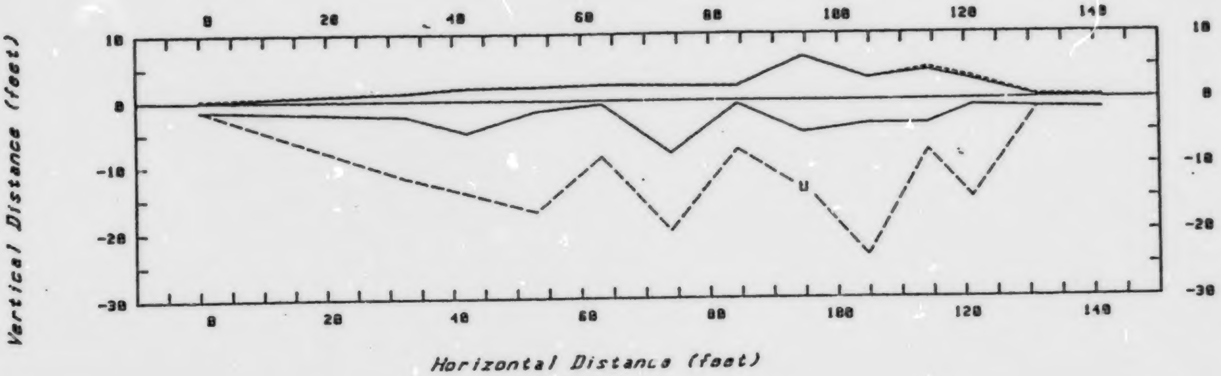
Adjacent Floe Thicknesses	1.7 ft
Maximum Sail Height	4.3 ft
Maximum Keel Depth	27.7 ft
Maximum Depth of Consolidation	26.0 ft

SUMMARY OF DIMENSIONAL RATIOS

Maximum Keel Depth/Maximum Sail Height	6.4
Maximum Consolidated Depth/Maximum Sail Height	6.0
Maximum Consolidated Depth/Adjacent Level Ice Thickness	15.3

FIGURE 2.2

PRESSURE RIDGE NO. 17
(after Geisel et al, 1982)



PRESSURE RIDGE NO. 18
(First-Year)
Position: Lat. 64° 16.9′ N
Long. 168° 45.1′ W
4/23/82
Floe Drift: Spd. .2 kts.
Course 241° True

Snow Cover: - - - - - - - - - - - - - - - -
Solid Ice Surfaces: ————————
Total Depth By Drilling: — — — — — — —
Sonar Depth: —— - —— - —— - ——
C: Consolidated Depth, Ice Below
U: Unconsolidated Depth, Ice Below

PRESSURE RIDGE NO. 18

SUMMARY OF PHYSICAL CHARACTERISTICS

Adjacent Floe Thicknesses	1.5 ft
Maximum Sail Height	6.5 ft
Sail Width (83'-131')	48.0 ft
Maximum Keel Depth	23.6 ft
Keel Width (0'-131.3')	131.3 ft
Maximum Depth of Consolidation	8.2 ft

SUMMARY OF DIMENSIONAL RATIOS

Maximum Keel Depth/Maximum Sail Height	3.6
Maximum Consolidated Depth/Maximum Sail Height	1.3
Maximum Consolidated Depth/Adjacent Level Ice Thickness	5.5

FIGURE 2.3

PRESSURE RIDGE NO. 18
(after Geisel et al, 1982)

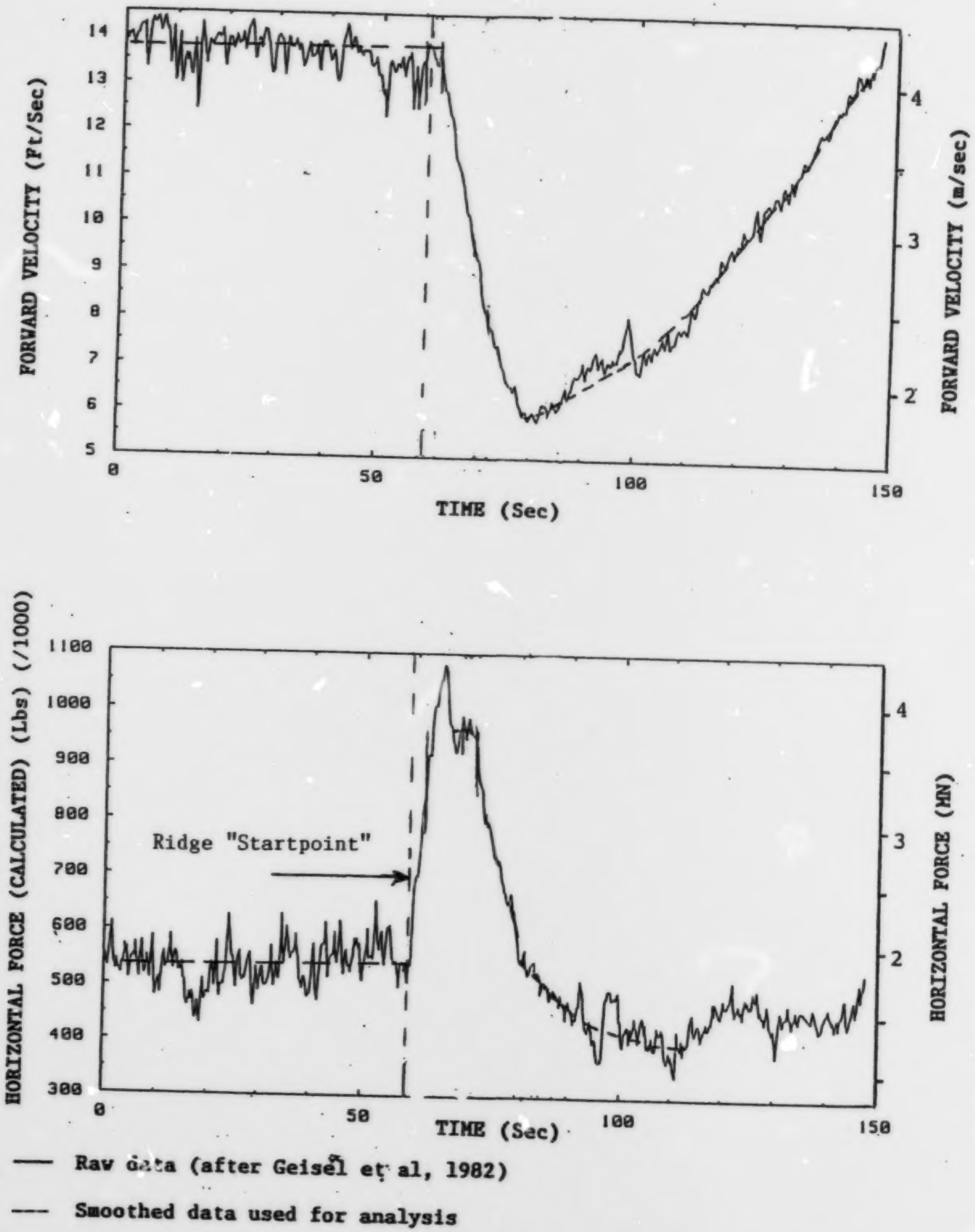


FIGURE 2.4

SMOOTHED VELOCITY AND FORCE TIME HISTORIES FOR RAMMING TEST OF RIDGE 17

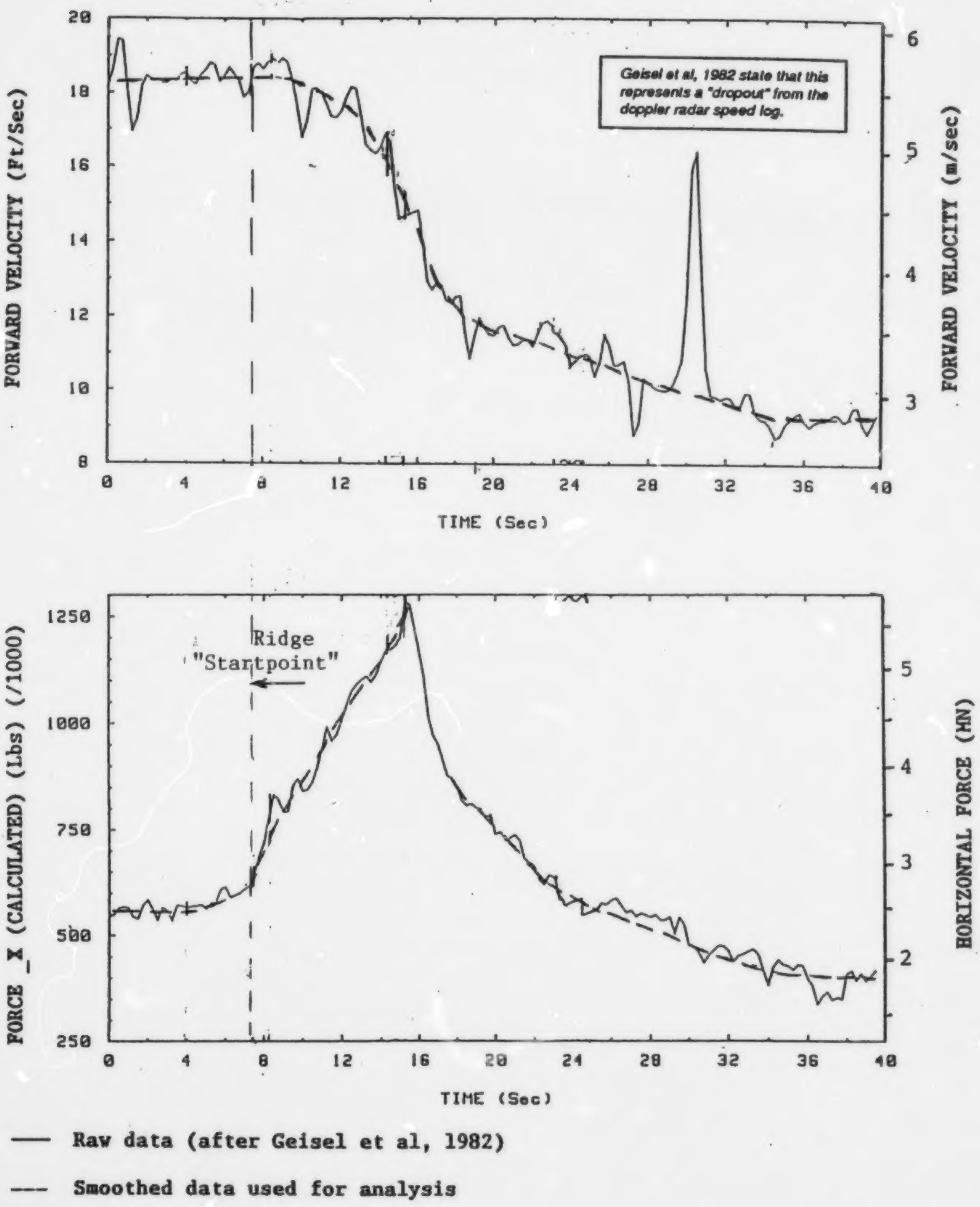
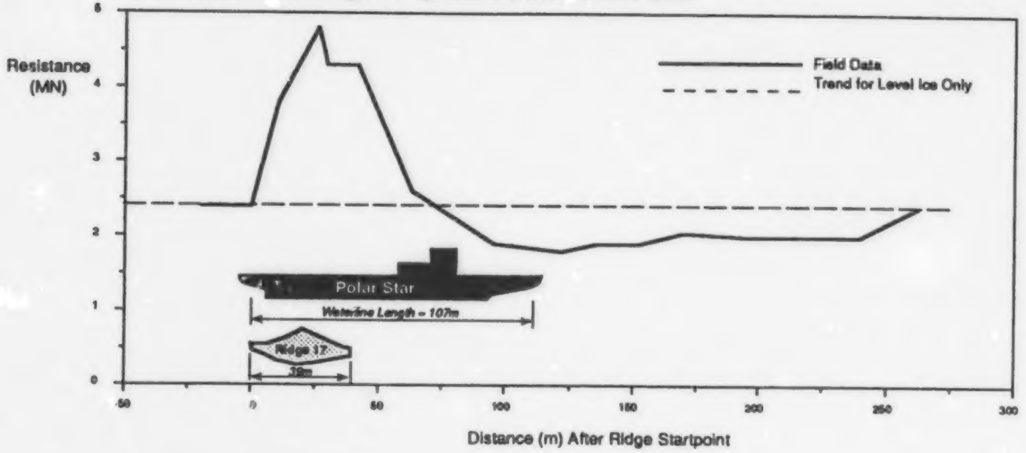


FIGURE 2.5

SMOOTHED VELOCITY AND FORCE TIME HISTORIES FOR RAMMING TEST OF RIDGE 18

Resistance Field Data:
Penetration of Ridge 17 by the USCGC Polar Star



Velocity Field Data:
Penetration of Ridge 17 by the USCGC Polar Star

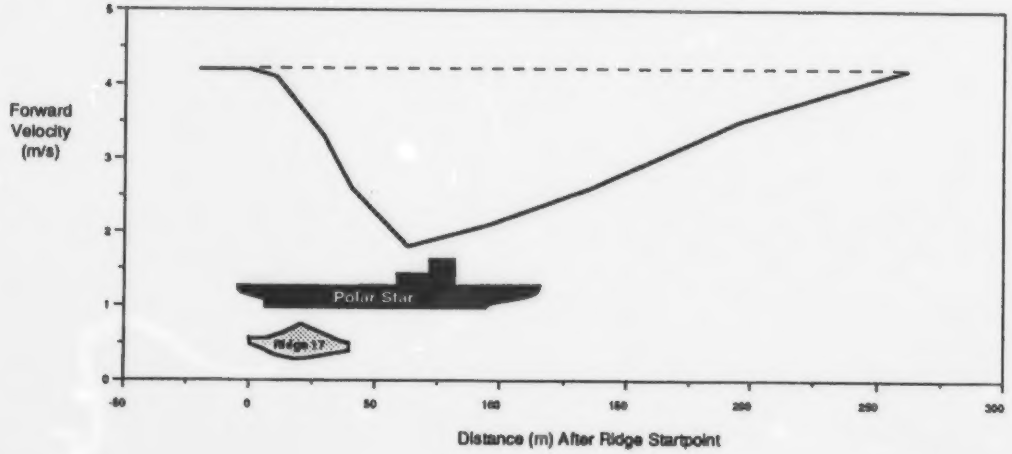
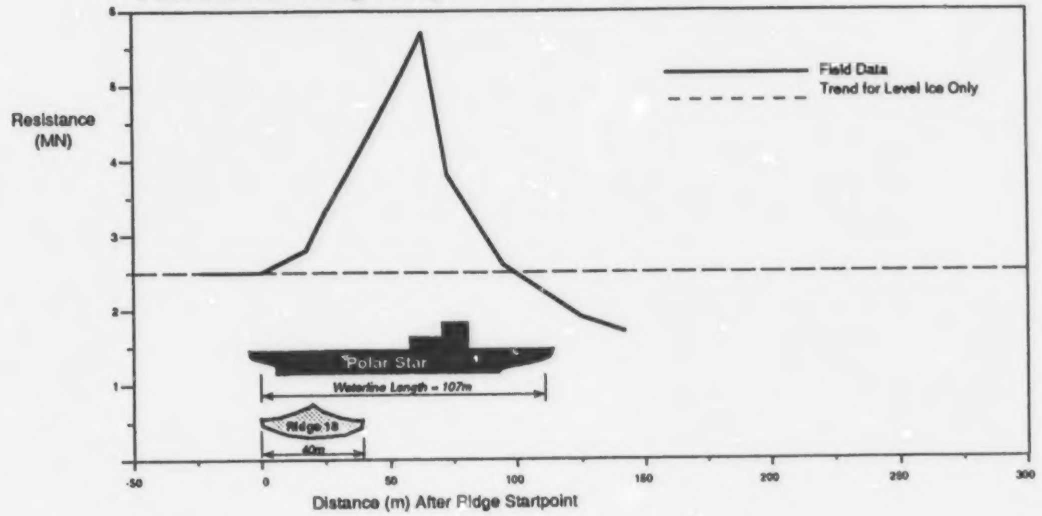


Figure 2.6

Resistance Field Data:
Penetration of Ridge 18 by the USCGC Polar Star



Velocity Field Data:
Penetration of Ridge 18 by the USCGC Polar Star

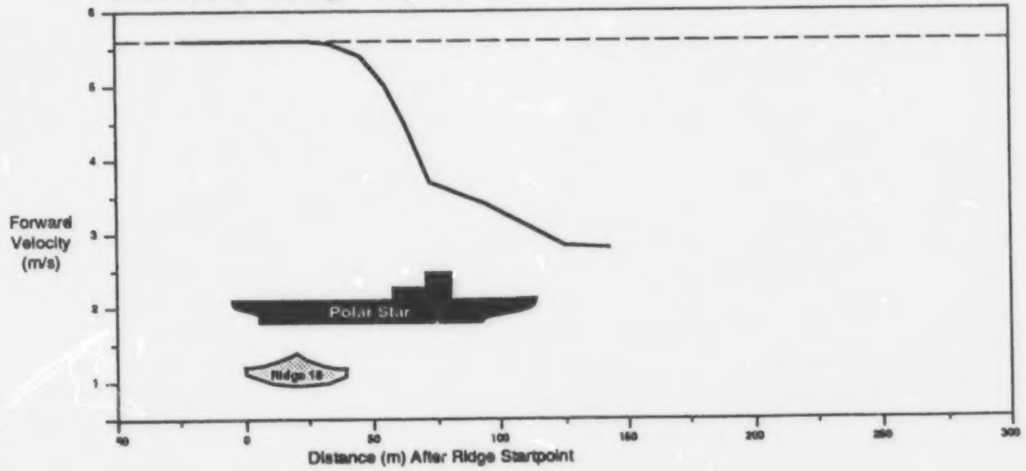


Figure 2.7

Figures 2.6 and 2.7 compare the field data with the trends (of resistance and velocity versus travel distance) that would have resulted had there not been a ridge in the ice sheet. The total work done by the ship for these two cases can be compared based on the areas under the solid line (for the field data) and under the dashed line (for a level ice sheet). For ridge 17, the magnitudes of these two areas are within 2% of each other. See figure 2.6. This observation suggests that the presence of a ridge in an ice sheet does not increase the total work done by the ship over the total "single pass" ramming sequence (i.e., from steady-state travel in level ice, through the ridge, and then back to steady-state travel in level ice). Of course, this is to be expected if the ship's thrust is held constant, which is typical of ramming operations.

The presence of a ridge in an ice sheet is important, however, as it causes an increase in the rate at which energy must be expended. This causes a reduction in ship speed (and possibly forces the ship to operate in the ramming mode) thereby increasing the transit time for the journey. For ridge 17, a total time of 150 sec was required for the POLAR STAR to travel the distance of record (i.e., 260 m) whereas only 62 sec would have been required for it to travel this same distance in level ice at the "pre-ridge" speed. Clearly, this increase in travel time will result in significantly greater fuel consumption for the field case (of a ridge in an ice sheet) than for that same level ice sheet only.

The field data indicate that the force exerted by the ice on the POLAR STAR as it exits the ridge is less than the "pre-ridge" resistance. See figures 2.6 and 2.7. There are a number of possible explanations for this. Differences in ice conditions (e.g., thickness, strength, snow cover) could be responsible for the observed variation. Also, the ship had lower speed as it exited the ridge which would contribute to a lower resistance.

Analyses were carried out to investigate the latter hypothesis. The measured resistance record for ridge 17 was compared to that which would be predicted for the adjacent level ice only, taking into account the changes in ship speed that occurred over the ridge transitting event. This was done using the following semi-empirical predictor of the level ice resistance of the POLAR STAR ships (which was developed by [5] on the basis of field tests conducted in the Bering Sea and Antarctica):

$$R_i = 3.6\ \rho_w g\ Bh^2 + 0.2\ \rho_w g^{1/2}\ B^{1/2}\ L\ Vh \qquad [2.1]$$

where: R_i = ice resistance
ρ_w = mass density of sea water
g = acceleration due to gravity
B = maximum beam of ship at waterline
h = ice thickness
L = length between perpendiculars
V = ship speed

Figure 2.8 compares the predicted resistance of the "level ice" component of the ridge to the total resistance measured for the ridge. For the latter part of the record for ridge 17 (when the ship was transitting level ice only) the predicted and the measured resistances show reasonable correlation. This agreement supports the latter hypothesis above as an explanation for the reduction in resistance which was measured after the ship had transitted ridges 17 and 18.

It should be noted that the above comparison, which is shown in figure 2.8, was difficult as there is a discrepancy between the measured "pre-ridge" resistance and the value predicted by equation 2.1. See [2] for further discussion of this issue. Consequently, the above comparison was carried out for the level ice thickness which produced a match between the predicted and measured "pre-ridge" resistances. This allowed a preliminary evaluation of the effect of speed on the "post-ridge" resistance and was sufficient to point out the importance of this factor.

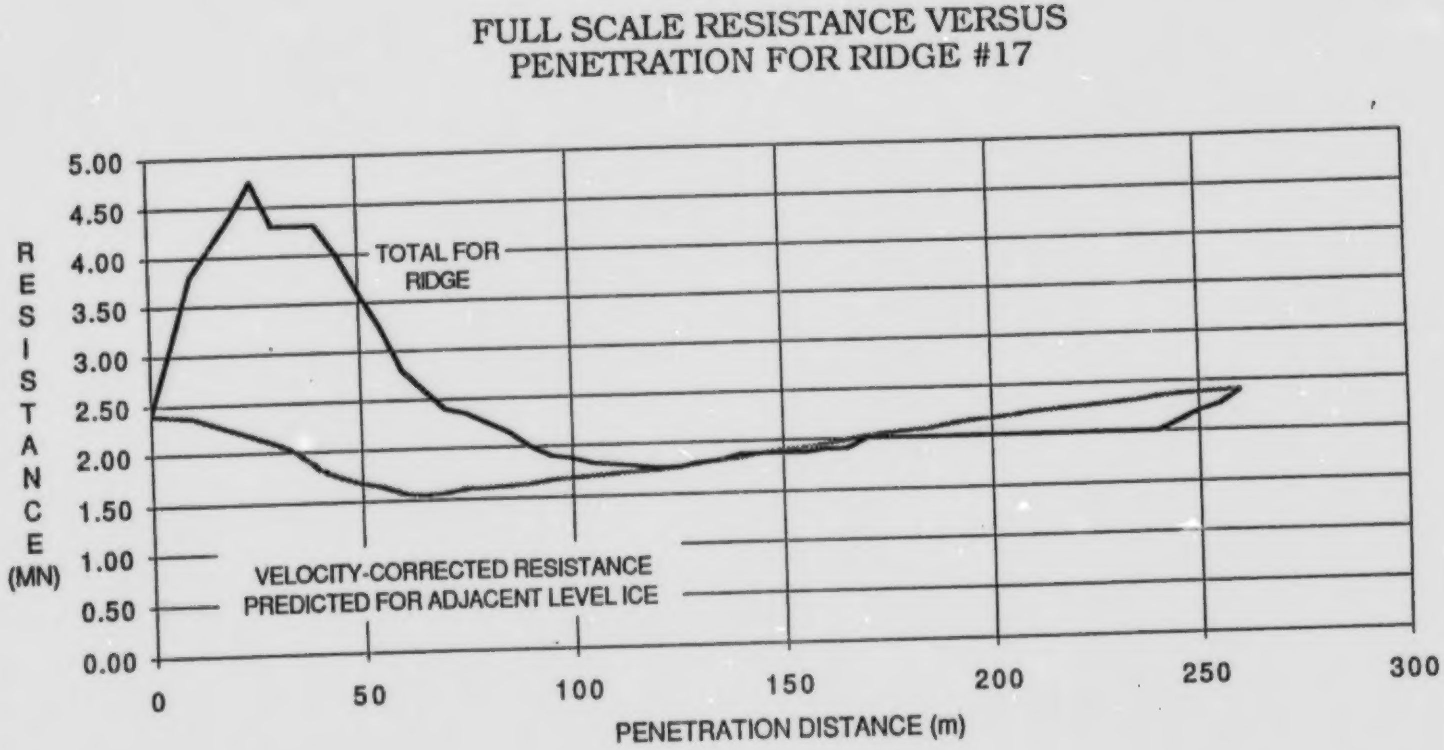

FULL SCALE RESISTANCE VERSUS
PENETRATION FOR RIDGE #17
RESISTANCE (MN)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
TOTAL FOR RIDGE
VELOCITY-CORRECTED RESISTANCE
PREDICTED FOR ADJACENT LEVEL ICE
0
50
100
150
200
250
300
PENETRATION DISTANCE (m)

Figure 2.8

2.3 General Description of Ridge Modelling Approach

The simplified ridge modelling approach proposed by the TDC is based on viewing the field ridge as a combination of the level ice and some additional ice. This additional ice is considered to be either sheet ice, or rubble ice, or a combination of both, depending on the degree of consolidation of the field ridge. Although the ridge modelling approach is not aimed at the exact duplication of a field ridge in the basin, it is useful to consider the "field" ridge that is represented by this conceptualization. See figure 2.9.

The penetration energy can be viewed as the sum of the following two components:

(a) the energy required to penetrate the "level ice" component of the ridge.

(b) the energy required to penetrate the "additional" ice in the ridge (i.e., the "incremental" energy of the ridge).

Figure 2.10 compares these two energy components.

The proposed ridge modelling approach is focused towards the simulation of the "incremental" energy of the ridge (i.e., item (b) above). The "incremental" energy (i.e., the energy associated with the additional ice) is represented by the energy requirements in excess of the "level ice" component. As the ship speed is variable during single-pass ramming, the "level ice" component is also variable. This was discussed in section 2.2 and figure 2.8. The incremental energy is thus defined with respect to the velocity-corrected level ice baseline.

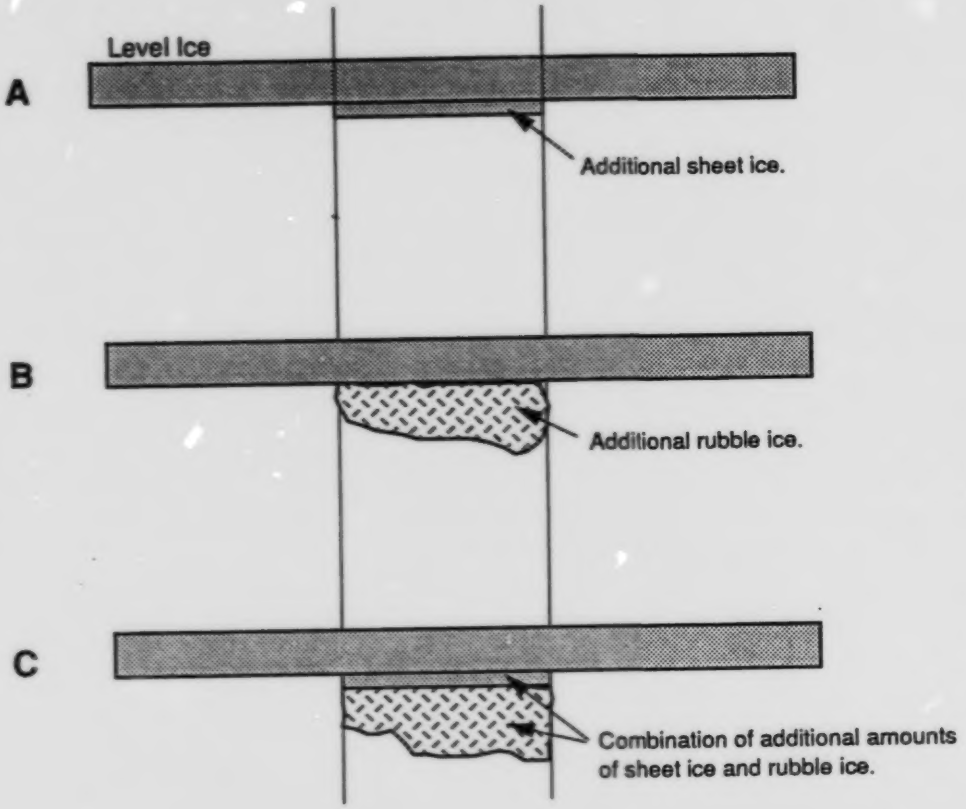
To predict the penetration energy of this additional ice, model tests were performed using level ice sheets and accumulations of broken ice only. As illustrated in figure 2.9, sheet ice is more appropriate for the modelling of multiyear ridges while broken ice, or a combination of sheet ice and broken ice, is more appropriate for the modelling of first year ridges. These two ice types were tested separately. Tests were conducted in the same manner as for level ice resistance testing (i.e., towed resistance testing).

This modelling method has the advantage of simplicity. These ice features are simple to produce in the basin, and furthermore, their properties can be controlled relatively well. Also, this testing method is simple.

However, the model test results cannot be applied directly as infinite sheets of level ice and rubble ice are tested in the basin while ridges are usually of limited width in the field. Therefore, an analysis of the penetration phase of these tests (when the bow enters the ice edge) is included with the proposed modelling approach. The proposed analysis procedure is illustrated in figure 2.11, and involves the following steps:

(a) the raw model test data are filtered to determine the mean resistance versus distance curve during the penetration phase.

(b) this filtered trace is repeated numerically and displaced to the right (see figure 2.11) by the ridge width of interest.


Level Ice
A
Additional sheet ice.
B
Additional rubble ice.
C
Combination of additional amounts of sheet ice and rubble ice.

Note: *The form of type A is similar to that of a multiyear ridge in nature, while the form of types B and C is similar to that of a partially-consolidated first year ridge in nature.*

Figure 2.9 Conceptualization of Field Ridge

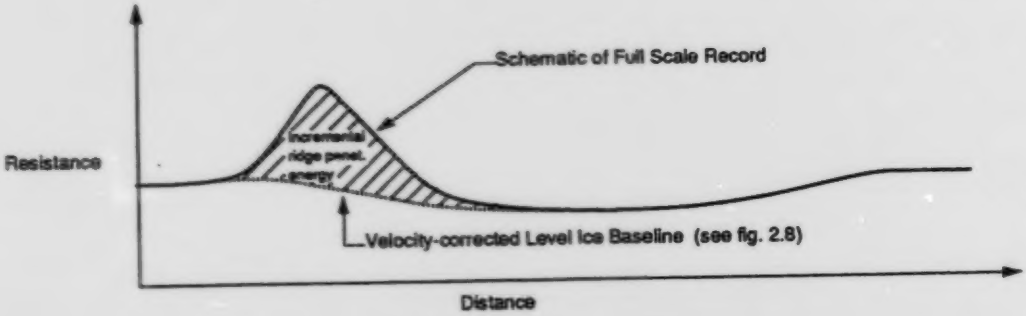

Schematic of Full Scale Record
Resistance
Incremental ridge penet. energy
Velocity-corrected Level Ice Baseline (see fig. 2.8)
Distance

Figure 2.10 Incremental Penetration Energy

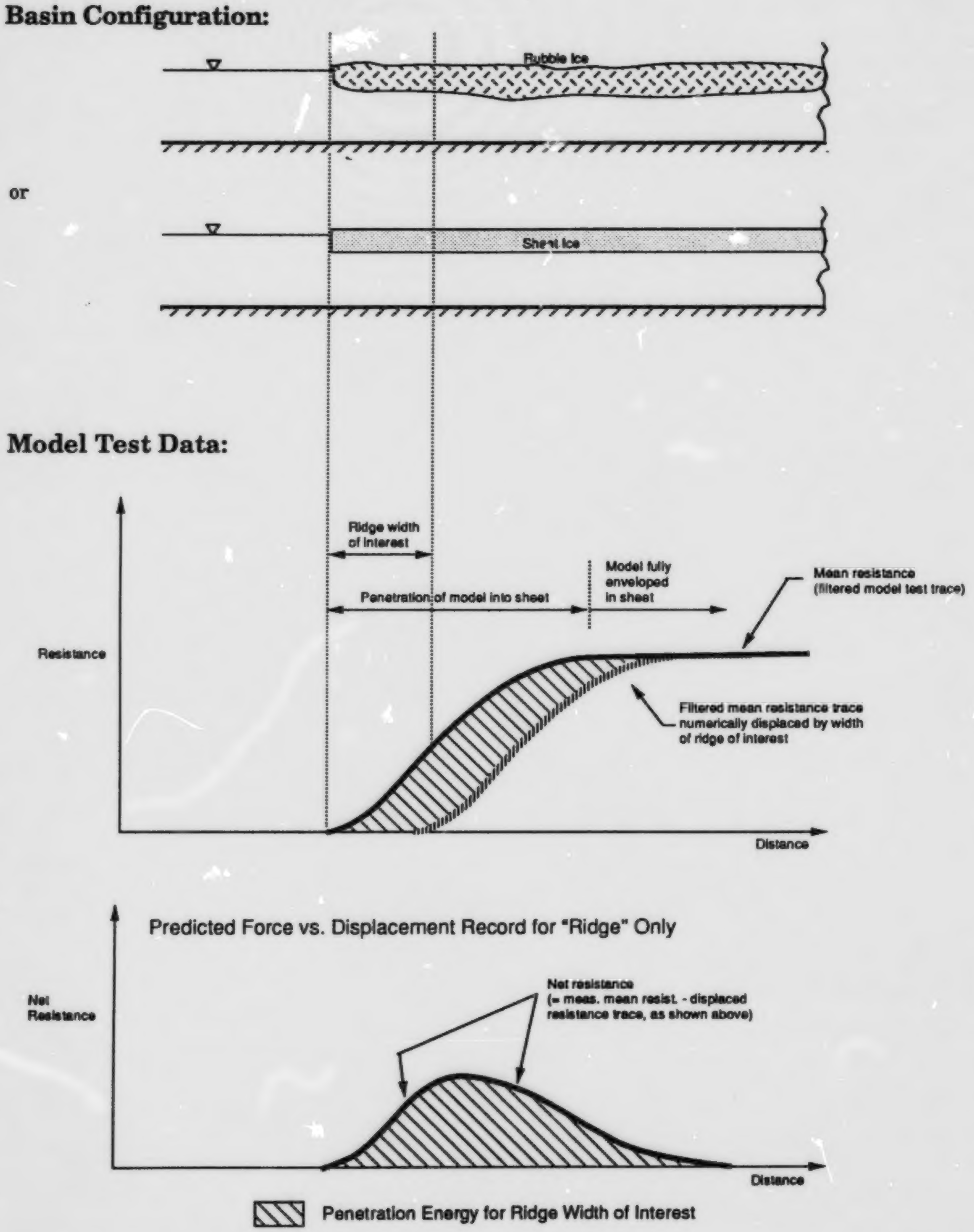

Basin Configuration:
Rubble Ice
or
Sheet Ice
Model Test Data:
Ridge width of interest
Penetration of model into sheet
Model fully enveloped in sheet
Mean resistance (filtered model test trace)
Resistance
Filtered mean resistance trace numerically displaced by width of ridge of interest
Distance
Predicted Force vs. Displacement Record for "Ridge" Only
Net Resistance
Net resistance (= meas. mean resist. - displaced resistance trace, as shown above)
Distance
▨ Penetration Energy for Ridge Width of Interest

Figure 2.11 Model Test Data Reduction

(c) the area between the measured force vs displacement trace and the displaced trace is determined. This area represents the work done to penetrate a distance which is equal to the ridge width of interest. This is assumed to be equal to the incremental energy for a ridge of the same width. This is not strictly valid, of course. For example, in the field, cracks may propagate from the ridge to the adjacent level ice. As these are not modelled, the model test results are expected to overpredict the ridge resistance.

(d) the force versus displacement curve for the "incremental" part of the ridge (see figure 2.10) is predicted by subtracting the displaced trace (see item (b) above for description) from the measured trace.

(e) the force versus displacement curve for the whole ridge is predicted by adding the curve for the incremental part of the ridge (i.e., item (d) above) to the velocity-corrected level ice resistance baseline. See figure 2.10.

3. MODEL TEST PROGRAM

3.1 Test Program Description

3.1.1 Test Setup

The ridge modelling approach outlined in section 2.3 was evaluated through a series of model tests. Tests were undertaken at FTL's laboratory in Kanata using EGAD-doped refrigerated ice with a 19.1:1 scale model of the USCGC POLAR STAR and a 22.5:1 scale model of the MV KIGORIAK. Table 3.1 summarizes key ballasting and surface preparation parameters for each of these models. For all tests, the model was fixed to the carriage such that it was free in the pitch, roll, and heave directions of motion and restrained in the other directions of motion (i.e., yaw, surge and sway). All tests were conducted at constant speed.

Figure 3.1 shows the general basin setup. For each test, the model was accelerated in open water so that it contacted the ice edge at the target speed. Level ice and rubble ice tests were conducted for each sheet. The model was first penetrated into the level ice. At the end of these tests, the sheet ice was broken up into ice pieces with dimensions of two to five times the ice thickness. These broken ice pieces were then placed in a channel in the centre of the basin to provide an accumulation of rubble ice for testing. Efforts were made to distribute the rubble ice uniformly in this channel. Wooden restraint strips or the adjacent level ice were used to restrain the rubble ice in the channel. Several rubble ice tests were conducted for each ice sheet. At the end of each run, the broken ice pieces were redeposited in the channel in preparation for the next test.

3.1.2 Test Documentation

The following parameters were measured during the tests:

(a) the horizontal force time history for the model,

(b) the carriage position time history,

(c) the separation between the ice edge and the bow at the waterline,

(d) properties of the model ice.

The horizontal force was measured using a strain-gauged force block which was inserted at the joint between the tow post and the model. The position of the carriage was measured using a shaft encoder on the carriage drive system.

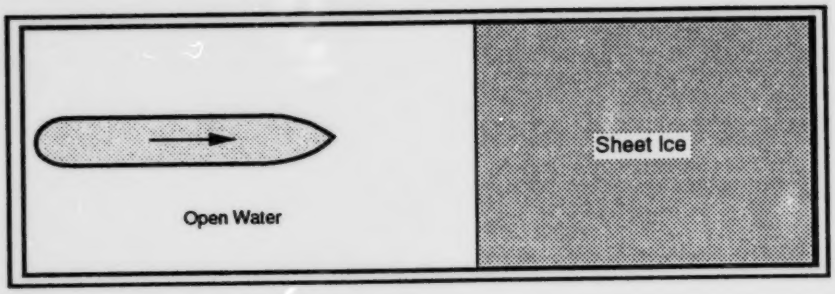
Both the horizontal force and displacement of the model were recorded using a digital data acquisition system. The major components of this system were Vishay 2120 strain gauge signal conditioners, low pass anti-aliasing filters, a Hewlett-Packard 9816 computer and an Analogue-Devices AD200 digitizing card. These test data were filtered at 20 Hz/channel and scanned at 100 Hz/channel.

A linear rule was used to measure the separation between the bow at the waterline and the ice edge.

The ice properties which were measured are described in section 3.2.

As well, the tests were documented photographically using 35 mm still cameras and video cameras.

Level Ice:


Sheet Ice
Open Water

Broken Ice:

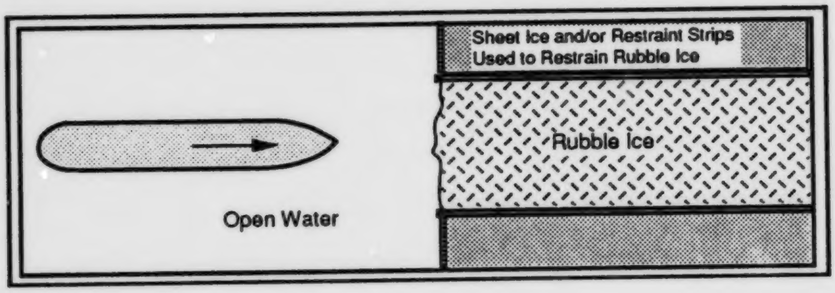

Sheet Ice and/or Restraint Strips
Used to Restrain Rubble Ice
Rubble Ice
Open Water

Figure 3.1 Schematic of Basin Setup

TABLE 3.1

KEY MODEL SETUP PARAMETERS

Parameter	USCGC POLAR STAR Meas. M.S. Value	 Extrap. F.S. Value	MV KIGORIAK Meas M.S. Value	 Extrap F.S. Value
Ice-Hull Friction Factor	0.14	0.14	0.14	0.14
Ballasting:				
Draft (M)	0.51	9.7	0.38	8.5
Pitch Period (sec)	1.5	6.6	1	4.7
Pitch Gyradius (M) (see Note 1 below)	0.25 LWL	0.25 LWL	0.25 LWL	0.25 LWL
Roll Period (Sec)	2.6	11.4	1.6	7.6

Notes: (1) Ballast weights were added to the models to achieve a pitch gyradius of 0.24 times the Length at Waterline (LWL). However, the pitch gyradius of the model in the ballasted condition was not measured.

(2) The pitch and roll periods were measured by pitching and rolling the model in the water.

(3) The ice-hull friction factor was determined by making measurements of the force required to pull an ice sample which was loaded with known weights over a horizontal wetted portion of the model surface.

3.1.3 Test Matrix

Tables 3.2 and 3.3 summarize the test matrix. A total of 30 tests were carried out with the MV KIGORIAK and a total of 29 with the USCGC POLAR STAR. Tables 3.4 and 3.5 list the ranges of variation for the model test parameters and the respective field data for ridges 17 and 18.

The model tests were conducted at speeds that were somewhat lower than the range for the field data, particularly for the tests with the POLAR STAR model. This lower range of test speeds was necessitated by the fact that FTL's basin is relatively small (i.e., 15.6 m x 4.5 m x 1.8 m deep). As the USCGC POLAR STAR is a large ship, this model was large in relation to the size of the basin. Problems were experienced with this model at speeds greater than 0.4 m/s. These included the production and reflection of waves when the model was accelerated in open water. (Efforts were made to accelerate the models relatively quickly in order to maximize the length of ice sheet for each test.) Consequently, it was necessary to restrict the maximum speed for the POLAR STAR tests to 0.4 m/s. This set of tests provided some data for evaluating the proposed ridge modelling approach. However, it necessitated that the model test data be corrected to the speed range of interest for model scale - full scale comparisons.

This was less of a problem for the tests done with the KIGORIAK model as the KIGORIAK is a smaller ship than the POLAR STAR. Consequently, this model could be tested over a range of speeds that was closer to the field data.

A large variation of ice thicknesses was tested. The range of tested ice thicknesses for level and broken ice brackets the average thicknesses for ridges 17 and 18.

A small number of tests were done with the KIGORIAK at a trimmed attitude. During ramming, the KIGORIAK trims significantly and the skeg is likely to contact the ice thereby causing crushing to occur. This greatly increases the resistance of the ship. In the basin, the motions of this ship will be reduced in comparison to full scale as only the incremental portion of the ridge (as opposed to the whole ridge) is being modelled. This distortion will tend to cause the model test results to underpredict the ridge transitting resistance for this ship. These tests were included to provide a preliminary understanding of this issue. However, detailed analyses of this issue have not been conducted in this study.

3.2 Ice Properties

Ice properties were measured using the techniques listed in Table 3.6. The results of the ice property measurements are shown in Tables 3.2, 3.3, 3.7 and 3.8.

TABLE 3.2

SUMMARY OF TEST MATRIX AND STEADY STATE RESISTANCES FOR TESTS CARRIED OUT WITH THE MV KIGORIAK

Sheet #	Test #	Ice Type	Ship Speed (m/s)	Avg Ice Thick (mm)	Ship Trim (deg)	Steady-State Resistance (N) (See Note 2)
1	1-1	Sheet	0.4	25	0	30
1	1-2	Sheet	0.8	25	0	60
1	1-3	Rubble	0.4	70	0	40
1	1-4	Rubble	0.8	70	0	40
1	1-5	Rubble	0.4	160	0	100
1	1-6	Rubble	0.8	149	0	90
2	2-2	Level	0.4	60	0	150
2	2-3	Level	0.8	59	0	210
2	2-4	Level	0.4	59	2.4 by stern	220
2	2-5	Level	0.8	59	2.4 by stern	190
2	2-6	Rubble	0.4	65	2.4 by stern	50
2	2-7	Rubble	0.8	65	2.4 by stern	60
2	2-8	Rubble	0.4	123	2.4 by stern	70
2	2-9	Rubble	0.8	118	2.4 by stern	80
2	2-10	Rubble	0.4	133	0	60
2	2-11	Rubble	0.8	132	0	90
2	2-12	Rubble	0.4	68	0	60
2	2-13	Rubble	0.8	83	0	70
3	3-1	Sheet	0.4	92	0	600
3	3-2	Sheet	0.8	89	0	700
3	3-3	Sheet	0.4	98	2.4 by stern	1100
3	3-4	Sheet	0.8	98	2.4 by stern	1900
3	3-5	Rubble	0.4	197	2.4 by stern	180
3	3-6	Rubble	0.8	197	2.4 by stern	200
3	3-7	Rubble	0.4	190	0	190
3	3-8	Rubble	0.8	198	0	210
3	3-9	Rubble	0.4	308	0	210
3	3-10	Rubble	0.8	260	0	300
3	3-11	Rubble	0.4	353	2.4 by stern	220
3	3-12	Rubble	0.8	323	2.4 by stern	210

NOTE: (1) All values are model scale.

(2) As the run length was very short, the measured steady-state resistances are first-order only. See section 3.3.

TABLE 3.3

SUMMARY OF TEST MATRIX AND STEADY STATE RESISTANCES FOR TESTS CARRIED OUT WITH THE USCGC POLAR STAR

Sheet #	Test #	Ice Type	Ship Speed (m/s)	Avg. Ice Thick. (mm)	Steady-State Resistance (N) (See Note 3)
4	4-1	Sheet	0.4	27	90
4	4-3	Rubble	0.4	122	80
5	5-1	Sheet	0.4	66	120
5	5-3	Rubble	0.4	210	100
6	6-1	Sheet	0.4	62	150
6	6-3	Rubble	0.4	122	110
6	6-5	Rubble	0.4	245	170
7	7-1	Sheet	0.4	94	320
7	7-3	Rubble	0.4	168	110
7	7-5	Rubble	0.4	343	230
DS1	DS1-7	Rubble	0.1	280	180
DS1	DS1-8	Rubble	0.2	277	190
DS1	DS1-9	Rubble	0.4	257	220
DS2	DS2-1	Sheet	0.1	50	n/a-See Note 2
DS2	DS2-2	Sheet	0.4	52	170
DS2	DS2-3	Rubble	0.4	129	100
DS2	DS2-4	Rubble	0.2	119	80
DS2	DS2-5	Rubble	0.1	106	60
DS2	DS2-6	Rubble	0.4	247	360
DS2	DS2-7	Rubble	0.2	243	350
DS2	DS2-8	Rubble	0.1	241	300
DS3	DS3-1	Sheet	0.1	92	n/a-See Note 2
DS3	DS3-2	Sheet	0.4	95	320
DS3	DS3-3	Rubble	0.1	160	100
DS3	DS3-4	Rubble	0.2	174	150
DS3	DS3-5	Rubble	0.4	170	140
DS3	DS3-6	Rubble	0.1	307	270
DS3	DS3-7	Rubble	0.2	352	350
DS3	DS3-8	Rubble	0.4	337	460

NOTES:

(1) All values are model scale.

(2) The model was only partially embedded (to about the point of maximum beam) during this test.

(3) As the run length was very short, the measured steady-state resistances are first-order only. See section 3.3.

TABLE 3.4
MODEL SCALE TEST PARAMETERS

Parameter	Model Scale Range of Variation USCGC POLAR STAR	 MV KIGORIAK
Hull Form	√	√
Type of Ice Cover	Sheet; Rubble	Sheet; Rubble
Ice Thickness (mm):		
- Level Ice	25 - 95	25 - 92
- Broken Ice	105 - 360	65 - 350
Ship Speed (m/s)	0.1; 0.2; 0.4	0.4; 0.8
Ship Trim	Even	Even; 2.4° by Stern
Scale Factor	19.1	22.5

TABLE 3.5
FIELD DATA FOR RIDGES 17 AND 18 IN MODEL SCALE UNITS

	Ridge 17		Ridge 18	
Scale Factor:	19.1	22.5	19.1	22.5
Ship speed (m/s) extrapolated to model scale units:				
• Entering Ridge	0.94	0.86	1.3	1.18
• Minimum during ramming event	0.41	0.38	0.66	0.61
Average ridge profile dimensions extrapolated to model scale units: (see Note 1)				
• Width (m)	2.1	1.7	2.1	1.8
• Thick. of consolidated mat'l (mm) (see Note 2)	47	40	84	71
• Thick. of unconsolidated mat'l (mm)	277	236	194	164
• Thick. of adjacent level ice (mm)	27	23	24	20

Notes: (1) See [1] for further information.
(2) This includes the areas of the sail (which was consolidated) and the consolidated material which was below the waterline. See [1] for further information.

TABLE 3.6
ICE PROPERTY MEASUREMENT TECHNIQUES

PROPERTY	MEASUREMENT TECHNIQUE
LEVEL ICE:	
Thickness profile	Vernier caliper
Flexural strength	In-situ cantilever beam tests
Elastic modulus	Measurements of the deflections of the ice sheet for a range of point loads.
BROKEN ICE:	
Thickness profile	L-shaped profiling rod
Density; Porosity	Measurements of the force required to submerge a known volume of the rubble in combination with a knowledge of the ice density.
Shear strength	Measurements of the vertical force required to shear a known volume of the rubble.

NOTE 1: The porosity, P, and the bulk mass density, ρ_b, were computed as follows:

$$P = 1 - \frac{F}{V_t\, g\, (\rho_w - \rho_i)} \qquad [3.1]$$

$$\rho_b = (1 - P) \bullet \rho_i \qquad [3.2]$$

where: F = force to submerge broken ice

V_t = total volume of ice column

g = acceleration due to gravity

ρ_w, ρ_i = mass density of water, ice

NOTE 2: The shear strength of the broken ice was determined by measuring the vertical force required to shear a column of the broken ice. Static vertical loads were applied over a 0.3 m x 0.3 m square plate to the broken ice. This load was gradually increased until a large, rapid vertical deflection occurred. At this point, the rubble was considered to have failed. The failure planes of the broken ice appeared to be vertical and the surface area of the failed region was very close to the surface dimensions of the loading plate. This test technique was adopted as it has also been used in the field to measure the shear strength of first year ridges [6]. Furthermore, this approach has the advantage of simplicity.

The shear strength of the broken ice, τ_s was computed as follows:

$$\tau_s = \frac{Fs - F_b}{4b\, h_k} \qquad [3.3]$$

where: F_s = force to shear the broken ice

F_b = net buoyant force on the failed column of broken ice

b = width of square loading plate

h_k = average depth of column of failed broken ice

TABLE 3.7

SUMMARY OF MODEL SCALE LEVEL ICE PROPERTIES: FLEXURAL STRENGTH AND ELASTIC MODULUS

Sheet #	Average Flexural Strength (kpa)	Average Elastic Modulus (kpa)
1	18	24,500
2	23	25,000
3	19	22,000
4	11	10,700
5	21	31,000
6	22	20,900
7	23	46,700
DS1	23	20,100
DS2	22	31,200
DS3	22	13,200

TABLE 3.8

SUMMARY OF MODEL SCALE BROKEN ICE PROPERTIES: POROSITY, BULK DENSITY AND SHEAR STRENGTH

Sheet #	Thickness of Ice Blocks (mm)	Porosity %	Bulk Density (kg/m^3)	Shear Strength (kpa)
DS1	70	32	640	0.4
DS3	95	43	540	0.3

NOTE: The density of the sheet ice was taken as 940 kg/m^3 for sheets DS1 and DS3 based on previous experience with this type of model ice. The above bulk densities were computed using this value.

3.3 Test Results

3.3.1 Raw Data and Data Reduction Procedures

Figures 3.2 to 3.4 show sample raw and reduced data for tests done with the KIGORIAK model. Figures 3.5 to 3.7 show sample raw and reduced data for tests done with the POLAR STAR model.. A complete set of raw and reduced data plots is provided in Appendices A to J.

Figures 3.2 and 3.5 show sample raw resistance and position time histories for tests done with the KIGORIAK and the POLAR STAR, respectively. As would be expected, high loads were measured at the start and end of the records. These reflect inertial loads produced by the starting and stopping of the model. The middle portion of the records reflect loads while the model entered and transited through the ice.

These raw data were reduced in a number of steps. The raw resistance versus distance relationship was first determined from the measured resistance and position time histories. See figures 3.3 (a) and 3.6 (a) for sample plots for tests done with the KIGORIAK and the POLAR STAR, respectively.

The mean resistance versus distance record was determined by filtering the data record digitally. The filtering rate was established iteratively by filtering the data for test 1-2 over a range of rates. The optimum filtering rate was selected based on a visual comparison of the raw and filtered records. The filtering rate was then standardized for all tests at 0.3 Hz. A relatively steep filter dropoff of 80 db/octave was used. In order to avoid a phase shift, the test data were filtered in both the forward and backward directions (i.e., from left to right and from right to left - see figures 3.3 (a) and 3.6 (a)), and then averaged.

Prior to the filtering operation, the raw data record for the portion of the test before the model contacted the ice edge was cropped and replaced with the open water resistance of the model. This was done to minimize distortion of the filtered record by the pre-ice edge data. Figures 3.3 (b) and 3.6 (b) compare the raw and filtered data records for sample tests done with the KIGORIAK and the POLAR STAR models, respectively.

The origin of the resistance versus distance record was then shifted to coincide with the ice edge. This was done based on the measured separation between the bow and the ice edge for each test. This provided a plot of the mean resistance vs distance for the penetration phase only. Figures 3.4 (a) and 3.7 (a) show sample shifted plots which compare the raw and filtered test data for tests with the KIGORIAK and POLAR STAR models, respectively. Figures 3.4 (b) and 3.7 (b) show the filtered test data only for these same tests.

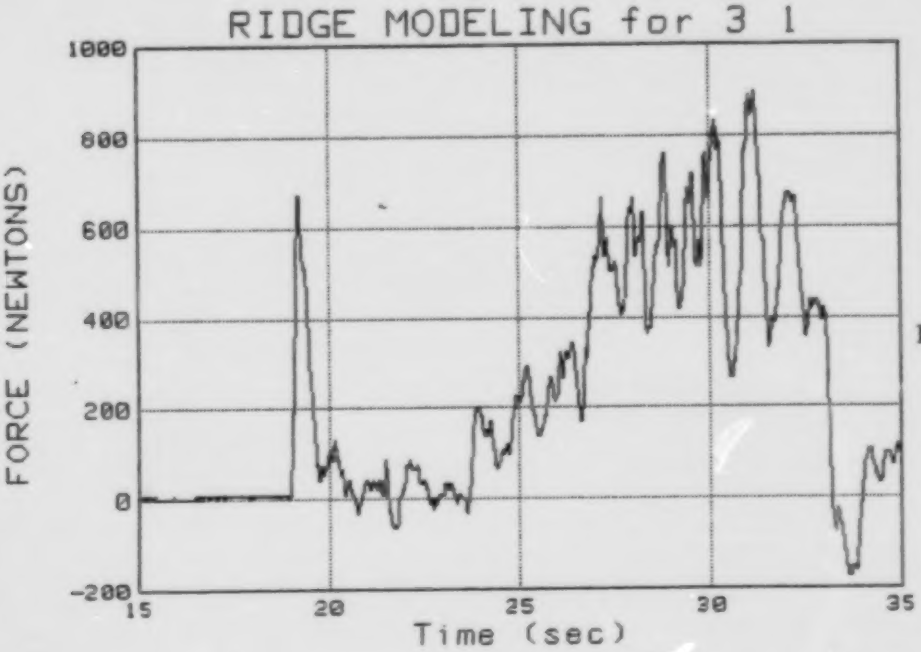


Figure 3.2(a)

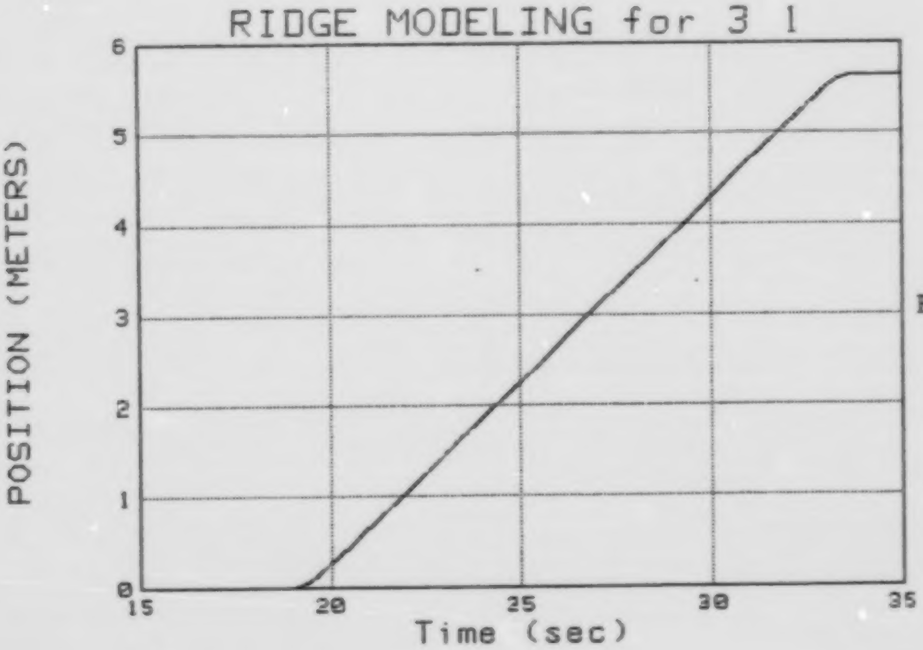


Figure 3.2(b)

Raw Data for Sample Test with
M.V. Kigoriak Model

Figure 3.2

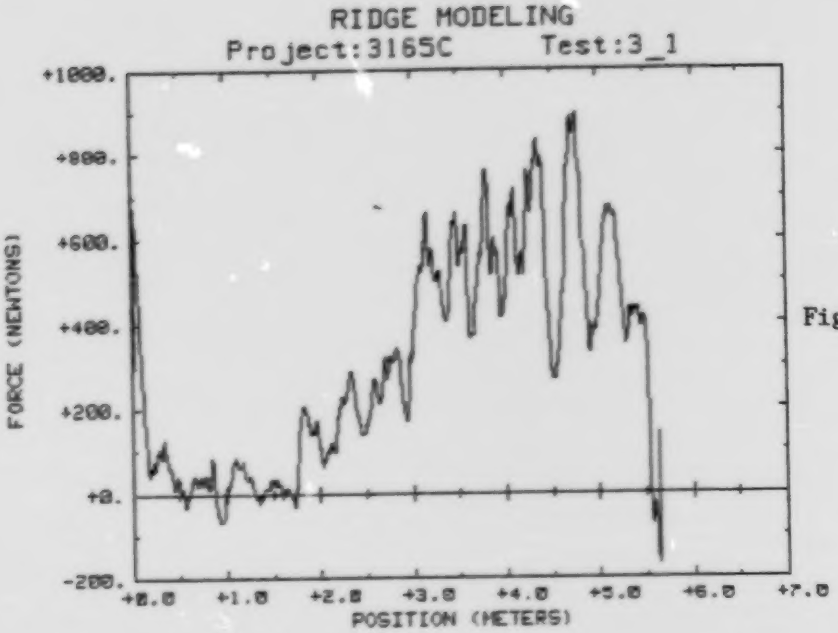


Figure 3.3(a)

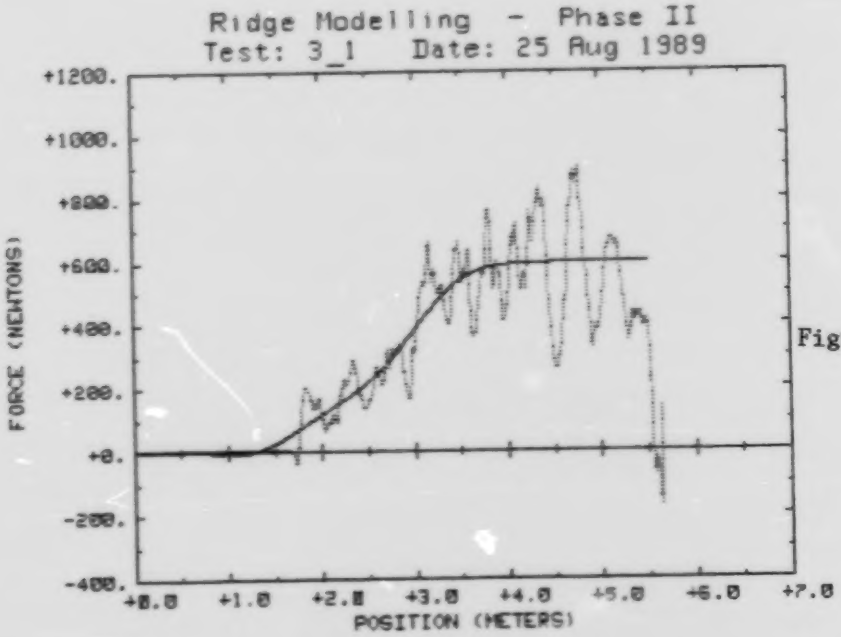


Figure 3.3(b)

Reduced Data for Sample Test
with M.V. Kigoriak Model

Figure 3.3

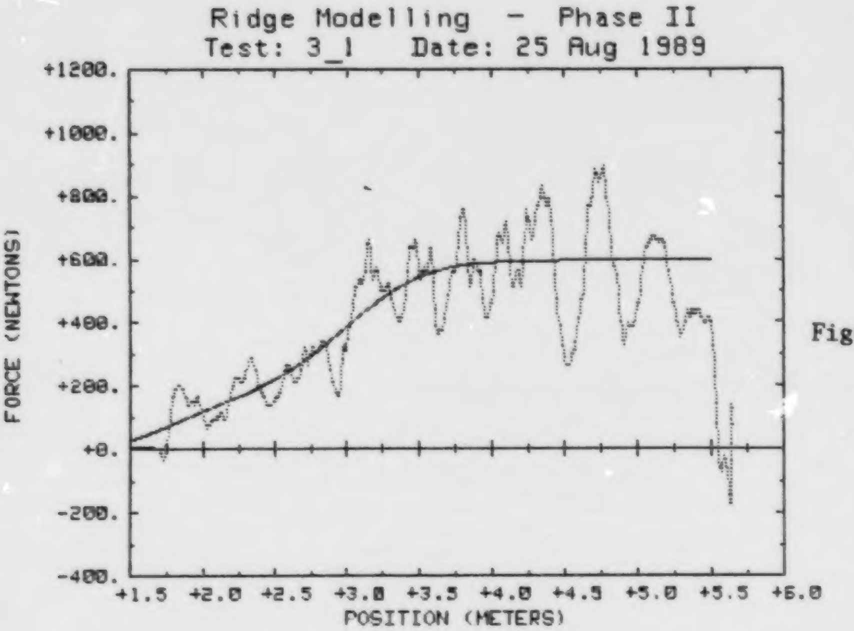


Figure 3.4(a)

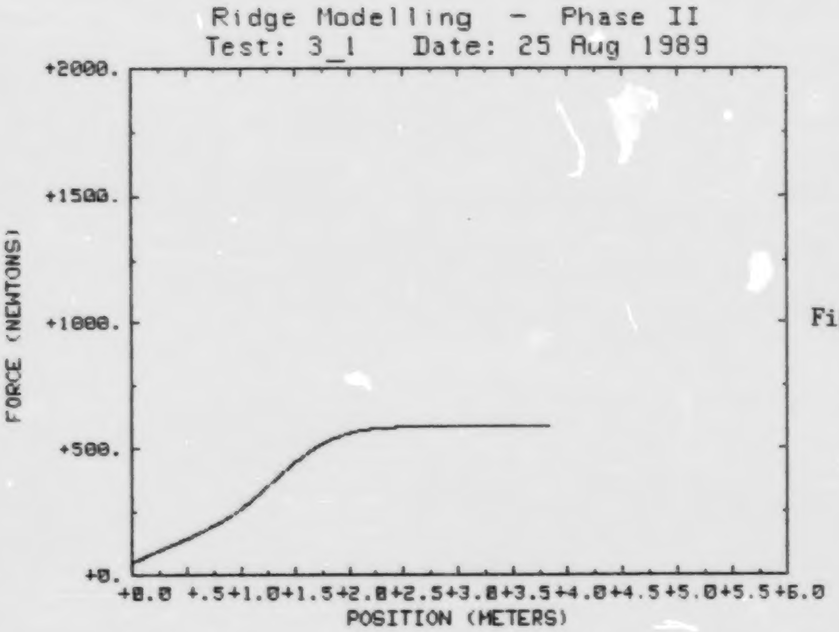


Figure 3.4(b)

Reduced Data for Sample Test
with M.V. Kigoriak Model

Figure 3.4

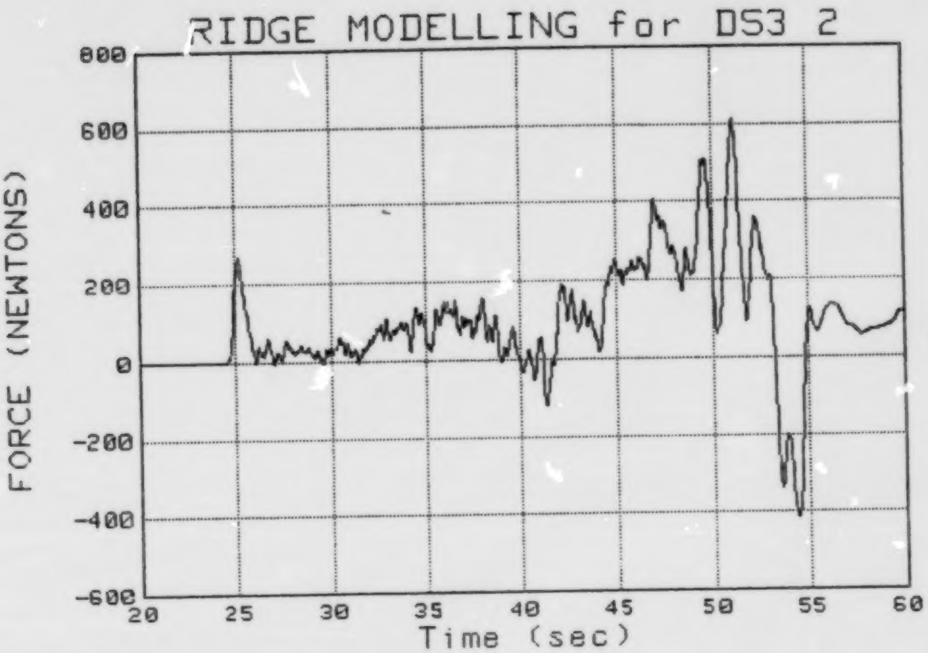


Figure 3.5(a)

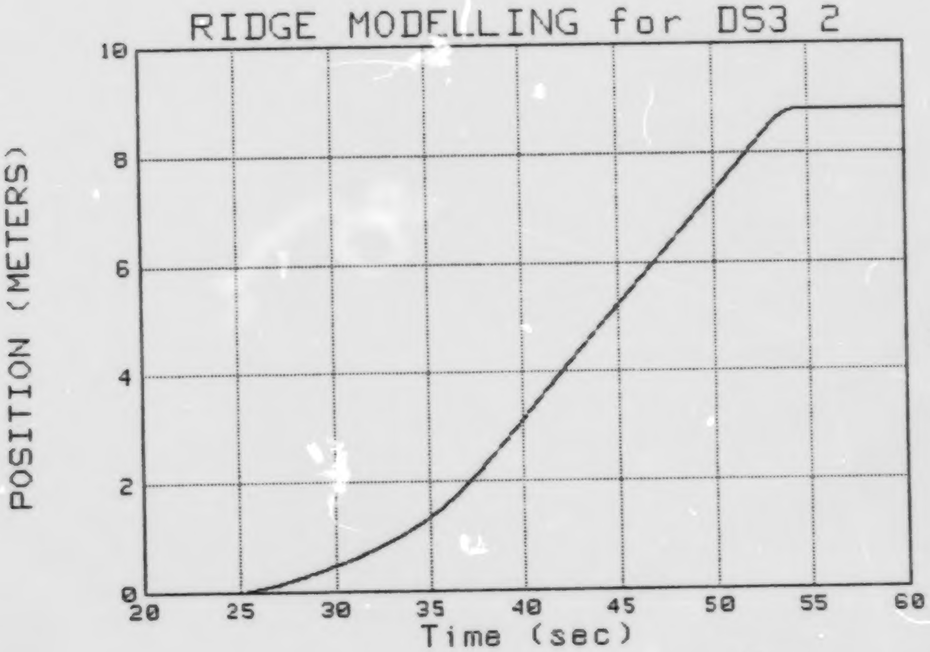


Figure 3.5(b)

Raw Data for Sample Test
with Polar Star Model

Figure 3.5

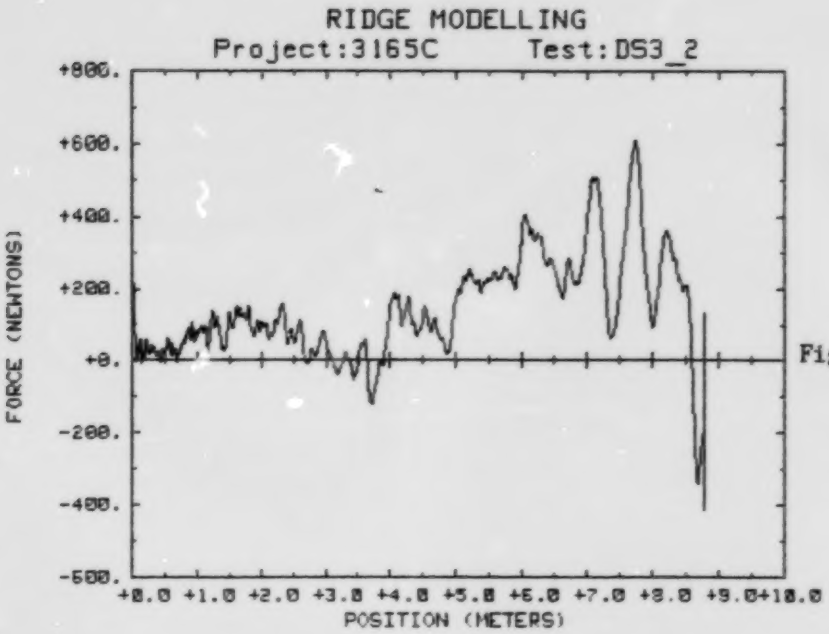


Figure 3.6(a)

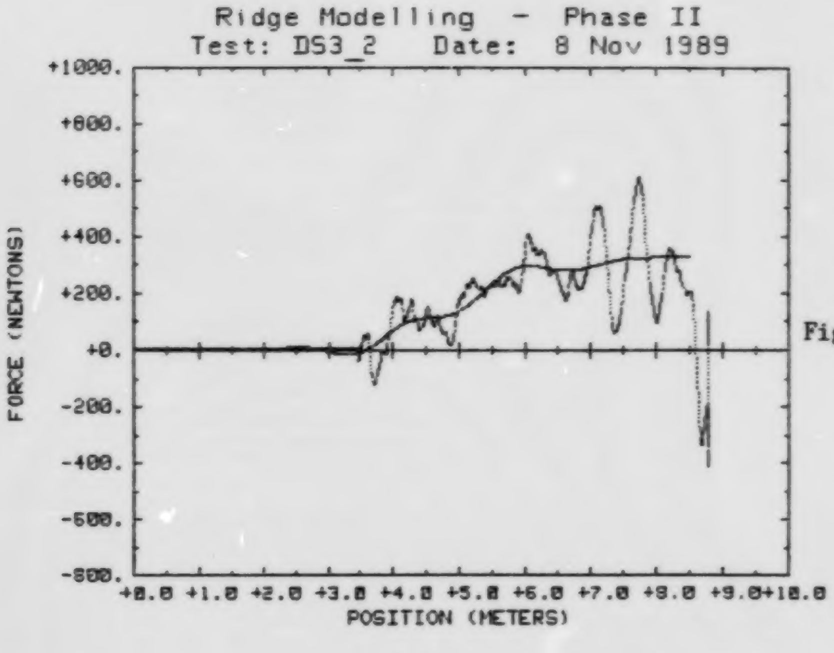


Figure 3.6(b)

Reduced Data for Sample Test
with Polar Star Model

Figure 3.6

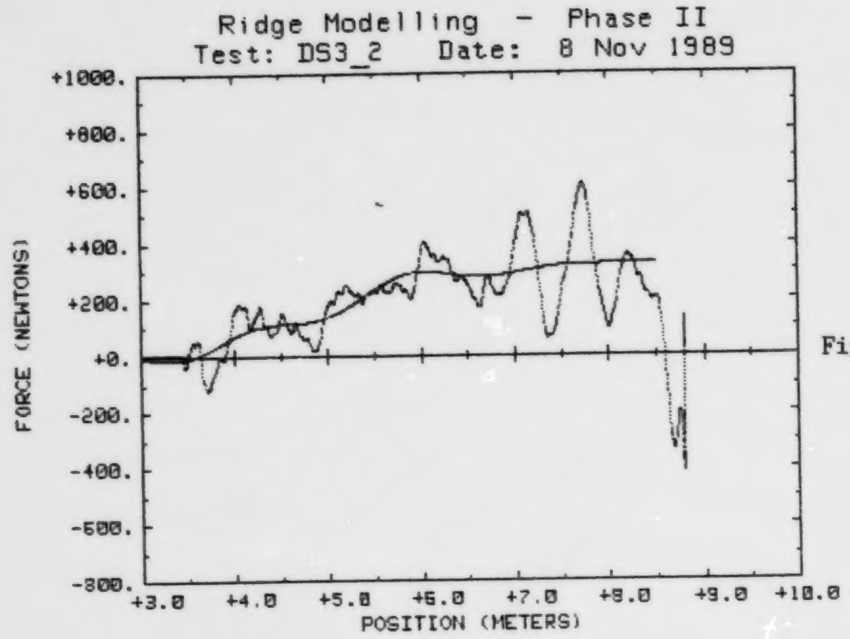


Figure 3.7(a)

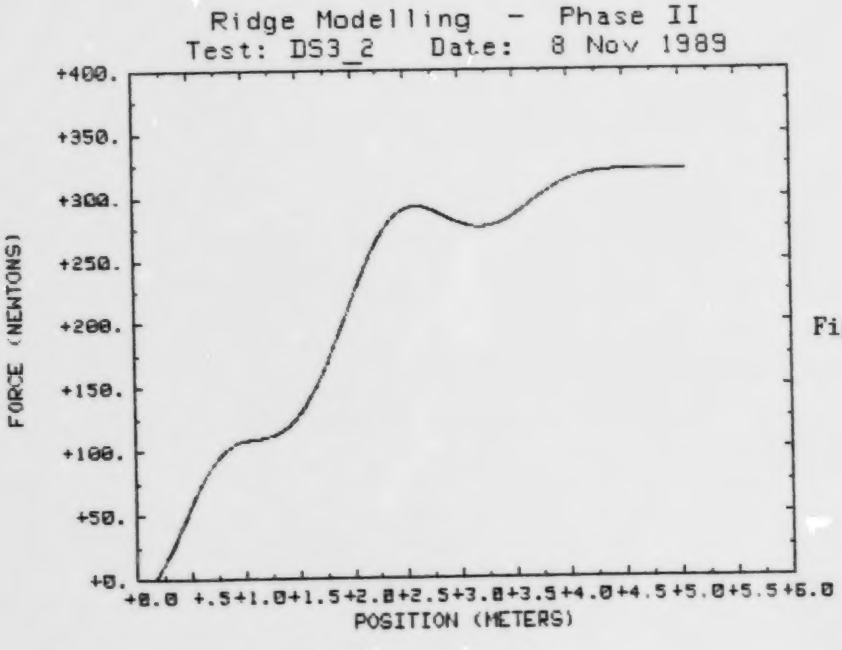


Figure 3.7(b)

Reduced Data for Sample Test
with Polar Star Model

Figure 3.7

3.3.2 Resistance During Penetration Phase

The shape of the resistance versus distance curve while the model penetrates the ice edge is of great interest. This parameter affects the rate at which energy is expended during the penetration phase.

The test data were non-dimensionalized by defining the non-dimensional resistance, R_{ND}, and travel distance, D_{ND}, as follows:

$$R_{ND} = \frac{\text{Resistance}}{\text{Steady-state resistance}} \qquad [3.4]$$

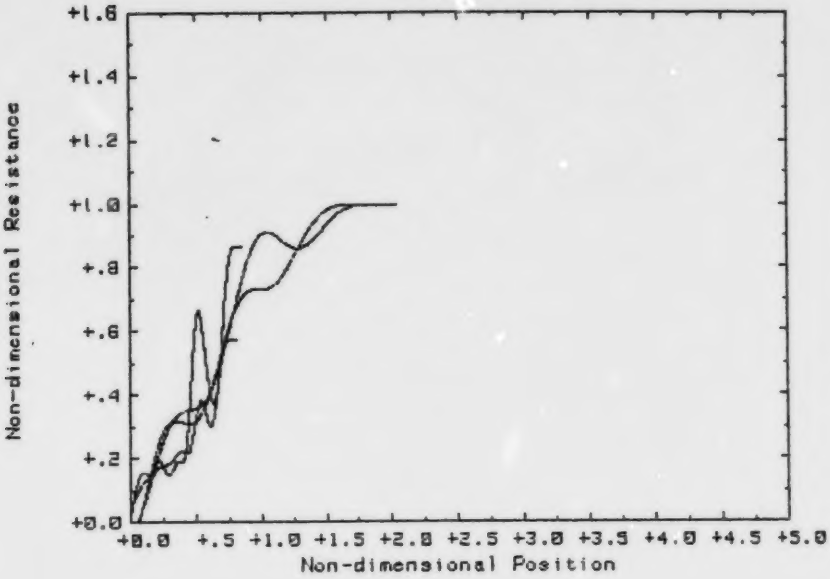
$$D_{ND} = \frac{\text{travel distance}}{\text{distance from bow to pt. of max. beam}} \qquad [3.5]$$

For most tests, the steady-state resistance (i.e., the denominator of equation [3.4]) was defined as the mean resistance over the latter part of the test. Most of the model was embedded in the ice at this point and hence, the steady-state resistance is comparable to the level ice resistance of the model for the sheet ice tests. Two tests were performed with the POLAR STAR model at low speed (i.e., 0.1 m/s) in which it was only partially embedded (i.e., up to about the point of maximum beam) in sheet ice (i.e., tests DS2-1 and DS3-1). These tests were carried out to provide additional data on the resistance during the penetration phase and to investigate the effect of speed. This penetration distance was insufficient to reach a steady-state resistance. Consequently, the level ice resistance of the model was used as the denominator for equation [3.4] for these tests. The results of level ice resistance tests conducted by [7] at the IMD were used for this purpose.

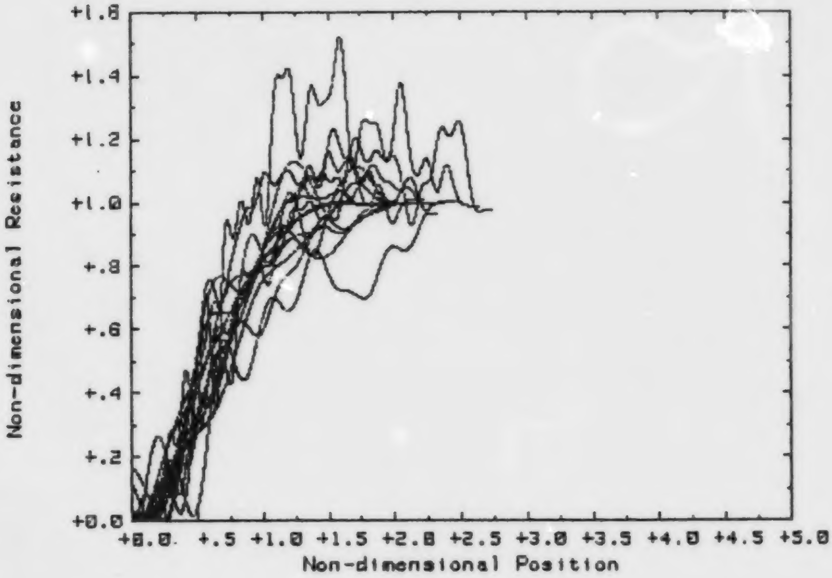
For the POLAR STAR model, the denominator of equation [3.5] was defined as the distance from the bow to the point of maximum beam at the waterline. For the KIGORIAK model, this distance was defined as the horizontal separation between the point of the bow at the waterline and the point of maximum beam of the model, which is below the waterline. This definition was adopted for the KIGORIAK as ice pieces tended to follow the reamers below the waterline to that point along the hull during the tests.

Figure 3.8 shows the relationship of the non-dimensional resistance to the non-dimensional travel distance for tests with the POLAR STAR model in sheet ice and broken ice. For both ice types, the steady-state resistance was reached after a travel distance of about 1.5 to 2.0 times the distance to the point of maximum beam. Figure 3.9 shows the same information for tests with the KIGORIAK model. The steady-state resistance was reached after a travel distance of about 2.0 and 2.5 times the distance to the point of maximum beam for the sheet ice and broken ice tests, respectively.

The test data for both models and both ice types are scattered. The dynamics of the towpost and the carriage system in the basin may be one contributing factor. However, most of this vibration was removed from the raw record by the filtering process. Compare figure 3.2(a) with figure 3.4(b) and figure 3.5(a) with figure 3.7(b).

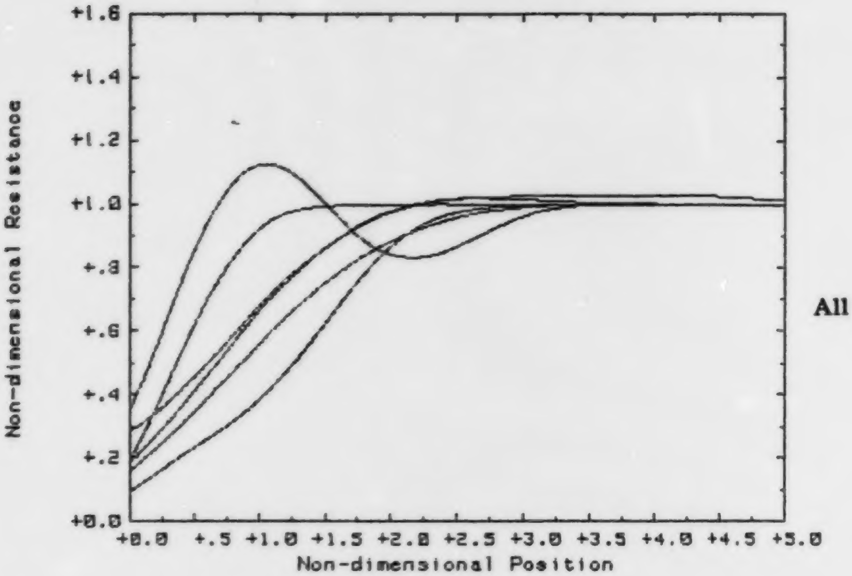


All Level Ice Tests

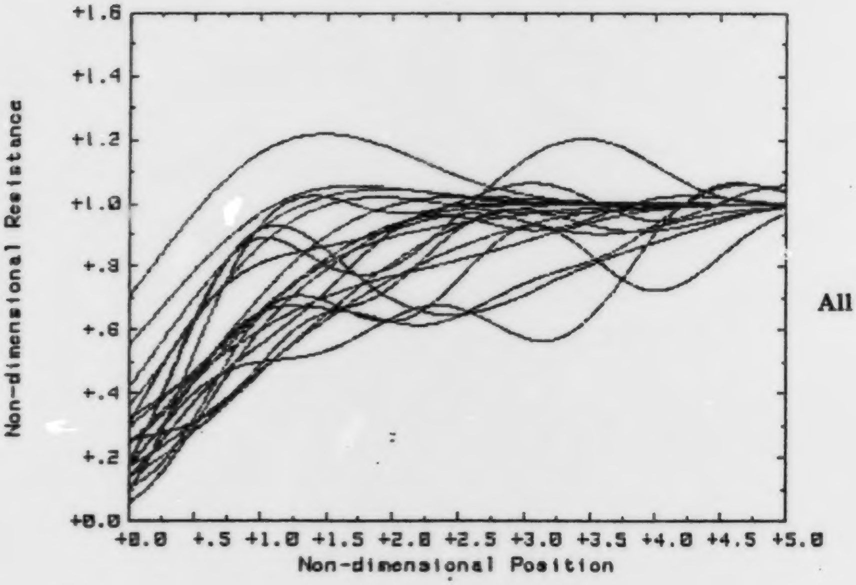


All Rubble Ice Tests

Figure 3.8
Non-Dimensional Resistance During Penetration Phase For
The Polar Star Model



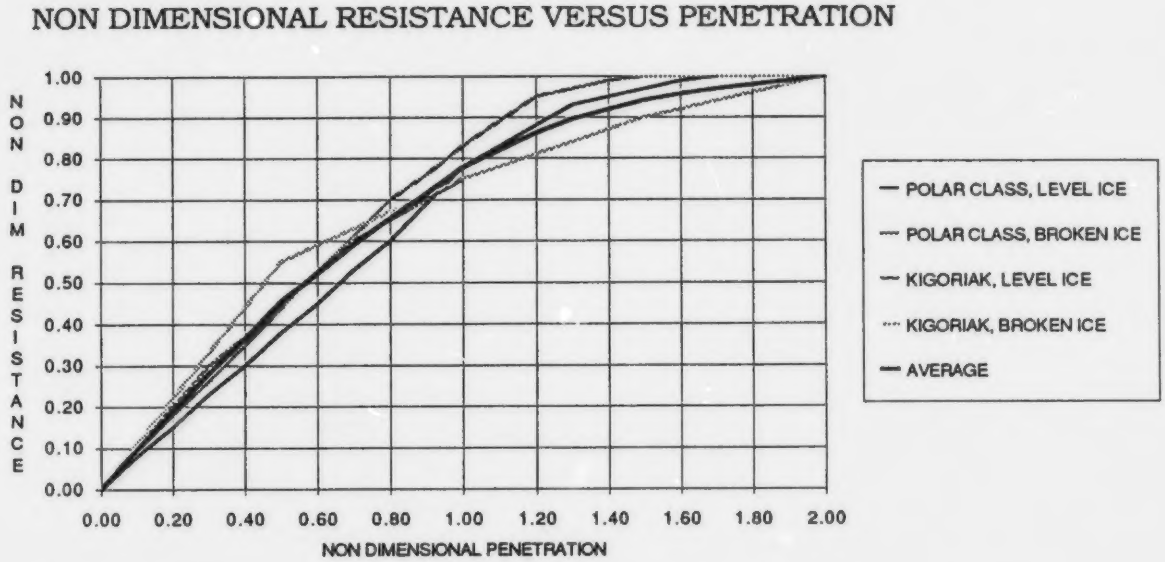
All Level Ice Tests



All Rubble Ice Tests

Figure 3.9
Non-Dimensional Resistance During Penetration Phase
For the Kigoriak Model

Figure 3.10


NON DIMENSIONAL RESISTANCE VERSUS PENETRATION
NON DIM RESISTANCE
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
NON DIMENSIONAL PENETRATION
POLAR CLASS, LEVEL ICE
POLAR CLASS, BROKEN ICE
KIGORIAK, LEVEL ICE
KIGORIAK, BROKEN ICE
AVERAGE

Figures 3.8 and 3.9 show that there is considerable variation between the filtered records for each test. This variation is related to non-symmetrical ice failures which occurred In level ice, cusps were formed unevenly which produced rolling motions of the model and a characteristic low frequency variation in the resistance time history. This assertion was corroborated by a review of the video records for the tests. This effect was most noticeable for tests in thick ice, as these tests resulted in the largest cusp sizes. This effect was more pronounced for the POLAR STAR than for the KIGORIAK as a result of the latter's spoon-shaped bow. Compare figures 3.4(b) and figure 3.7(b). The data records obtained during the rubble ice tests also show low frequency variations. However, these test results are more random which is believed to reflect the more variable properties of the rubble ice. These observations point to uneven ice failure processes as a source of the variations shown in figures 3.8 and 3.9.

Figure 3.10 plots the average curves for both models for both ice types. The differences between the averages for each case are relatively small and are within the scatter of the individual test data.

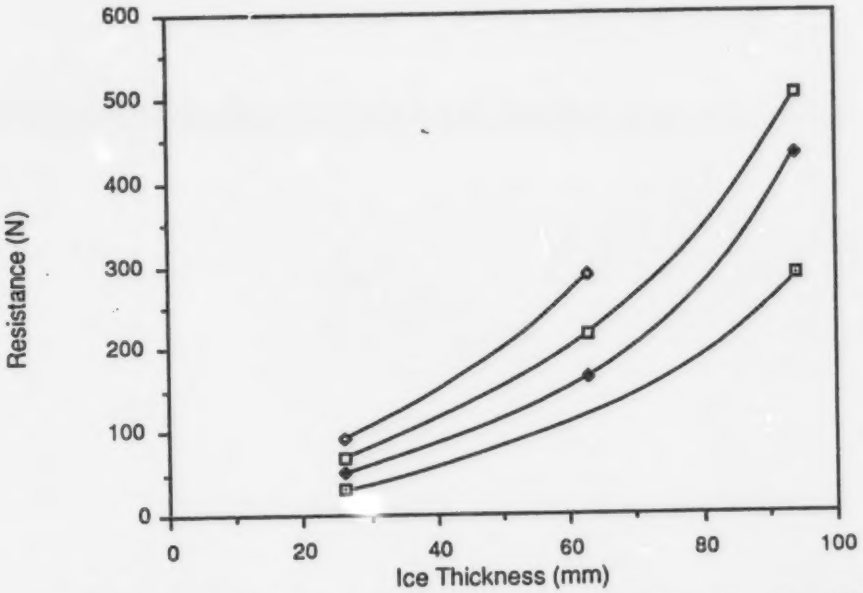
3.3.3 Steady-State Resistance

The main objective of this test program was to investigate the proposed approach to ridge modelling rather than the collection of data to determine the steady-state resistance of the models in level ice and broken ice. As FTL's basin is relatively short, only a limited length of run was possible for each test. Consequently, the distance over which steady-state data could be collected was less than one ship length. Therefore, while the results of this program with respect to steady-state resistance can only be considered to be first-order, they are useful for a preliminary evaluation of the proposed ridge modelling approach.

Tables 3.2 and 3.3 summarize the measured mean steady-state resistances in rubble ice and level ice for the KIGORIAK and POLAR STAR models, respectively. The level ice resistances measured during this project were not utilized for analysis as more reliable data were available from the IMD for the POLAR STAR [7] and for the KIGORIAK [8]. Figures 3.11 and 3.12 show these IMD test results.

Figures 3.13 and 3.14 plot the measured steady-state resistances in rubble ice as a function of thickness for the POLAR STAR and KIGORIAK models, respectively. These test results are insufficient to define the speed dependence of rubble ice resistance, as the effect of this parameter is within the scatter of the data. In the absence of other data to define, the rubble ice resistance of the POLAR STAR and the KIGORIAK, these data were used in subsequent analyses. For these analyses, the rubble ice resistance was considered to be a function of thickness only and to be independent of speed. See figures 3.13 and 3.14. This allowed a preliminary evaluation of the proposed ridge modelling approach. However, this approach, and these data, should be reviewed as more accurate data become available.

The test data provide some understanding of the effect of trim on the steady-state resistance of the KIGORIAK model. The broken ice resistance is not sensitive to this parameter. See figure 3.14. For level ice, this parameter was relatively insignificant for tests done with an ice thickness of 60 mm (i.e., 1.4 m full scale). See table 3.2. However, the resistance for an ice thickness of about 95 mm (i.e., 2.1 m full scale) was greatly increased by trimming the model. The resistance of the model in the trimmed condition was about 1.5 to 3 times that for the even trim case. See table 3.2. This reflects the fact that the skeg of the KIGORIAK contacted the ice edge directly and that ice failure occurred by crushing. This ice-skeg contact only occurred for the thickest ice which was tested. Apart from this observation, the test data for the trimmed condition were not used in subsequent analyses.

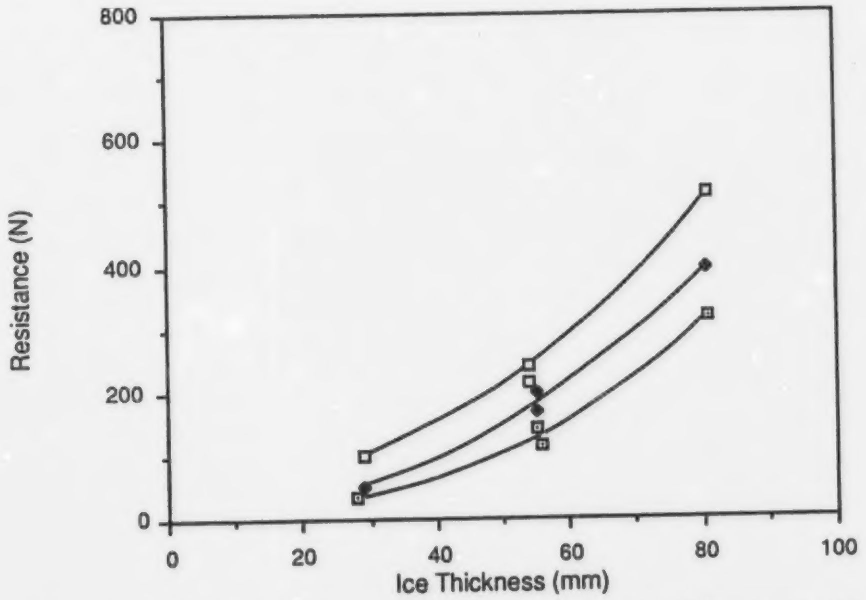


Speed (m/s)			
0.13	35-.38	.71-.76	1.1
⊡	◆	□	◇

Notes:1 The ice flexural strength was 18.3 kpa.

2 The ice-hull friction factor was 0.10.

Figure 3.11 Model Scale Ice Resistance Measured by the IMD of the USCGC POLAR STAR



Speed (m/s)		
0.2	0.5	1.0
⊡	◆	□

Notes:1 The mean ice flexural strength was 28.5 kpa.

2 The ice-hull friction factor was 0.11

Figure 3.12 Model Scale Level Ice Resistance Measured by the IMD of the M.V. KIGORIAK

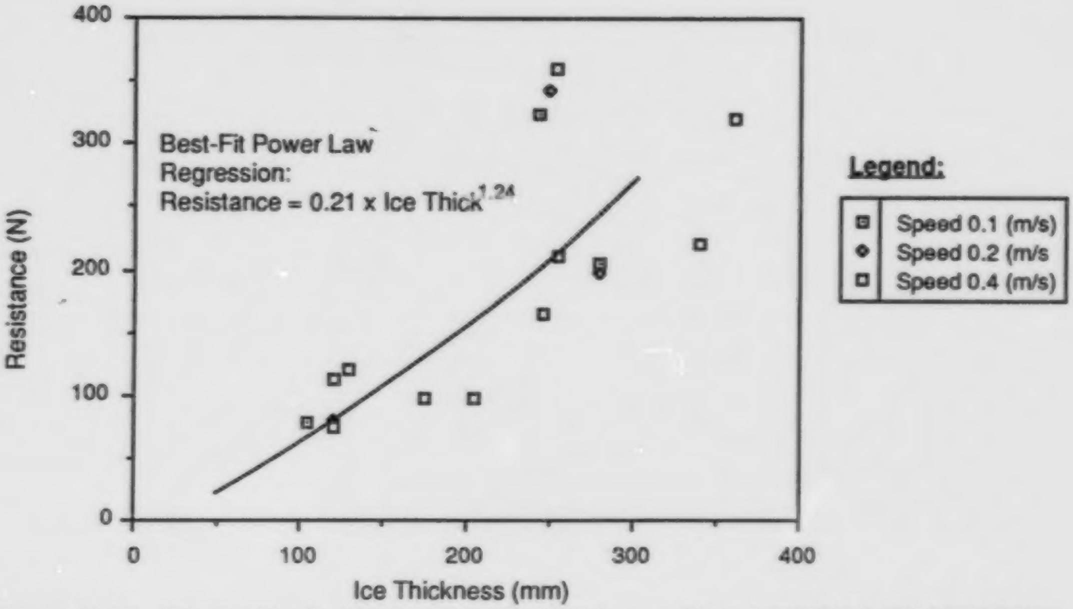


Figure 3.13 Model Scale Broken Ice Resistance of the USCGC POLAR STAR

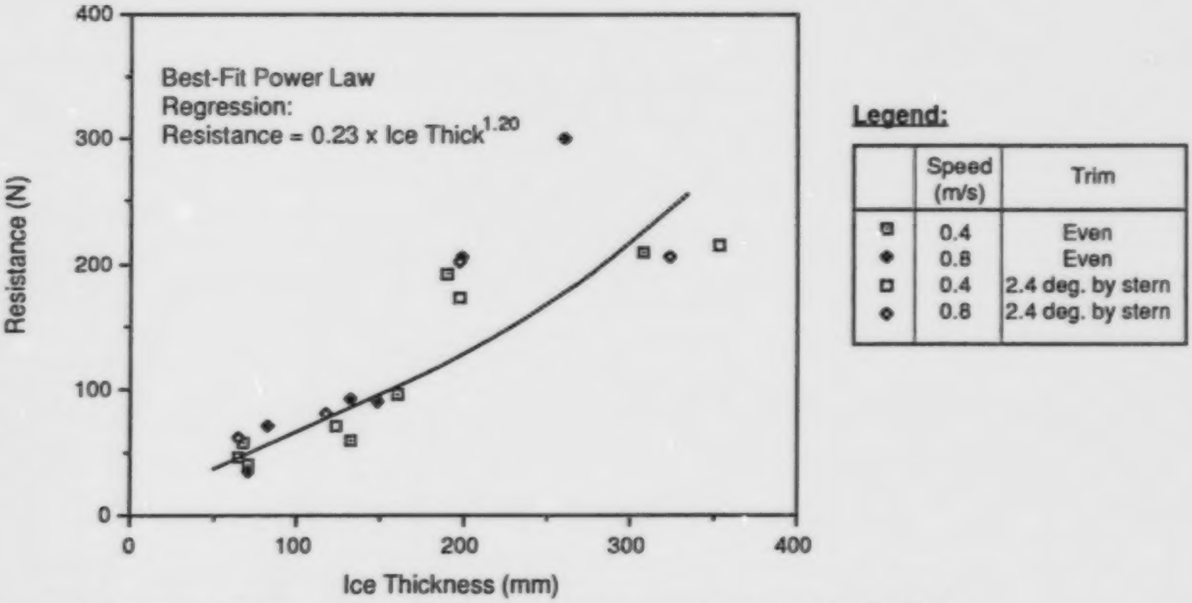


Figure 3.14 Model Scale Broken Ice Resistance of the M.V. KIGORIAK

4.0 ANALYSIS AND DISCUSSION OF TEST RESULTS

Two general types of analyses have been conducted, as follows:

(a) Comparisons and analyses of the penetration energy. The following has been carried out:

- POLAR STAR: Full scale-model scale comparison for ridges 17 and 18.
- KIGORIAK: Prediction of the incremental penetration energy for this ship for ridges 17 and 18.

(b) Full scale-model scale comparison of resistance versus distance curves for selected tests.

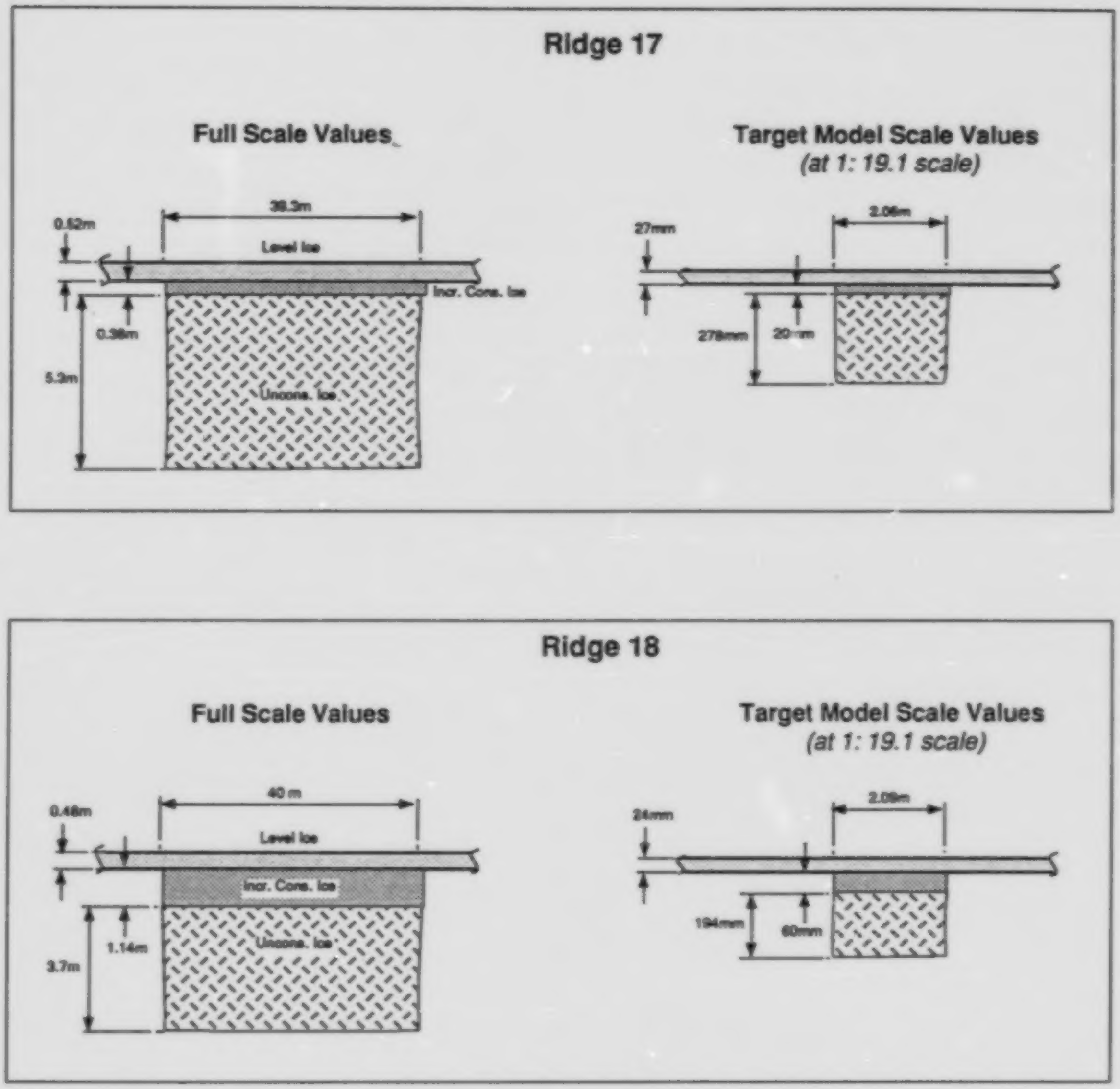
4.1 POLAR STAR and KIGORIAK: Penetration Energy

4.1.1 POLAR STAR: Full Scale-Model Scale Comparison for Ridges 17 and 18

This section compares the model scale and full scale incremental penetration energies for the POLAR STAR in ridges 17 and 18. For this comparison, the measured field ridge profiles have been simplified to reflect the average depths of consolidated and unconsolidated material in the ridge. Figure 4.1 illustrates the "average" field ridges that were used for this comparison.

The model test data were used to provide a prediction of the incremental penetration energy for these "average" ridges. Table 4.1 summarizes this comparison. The first step in this analysis was to use the model test data to predict the model scale incremental penetration energy for the consolidated and unconsolidated portions of ridges 17 and 18.

As discussed in section 3, the model tests were conducted at lower speed than the range of scaled speeds for the field tests with ridges 17 and 18. Consequently, it was necessary to apply a velocity correction to the model test data. For this preliminary comparison, the IMD test results (see figure 3.11) were used to predict the speed dependence of the penetration energy in level ice. Table 4.1 lists the range of scaled speeds which occurred during the field tests. The mid-range value was selected as a basis for comparison. The model test data measured for rubble ice were used directly for this comparison as these data indicated that the effect of speed on rubble ice resistance is small.


Ridge 17
Full Scale Values
Target Model Scale Values
(at 1: 19.1 scale)
38.3m
0.52m
Level Ice
Incr. Cons. Ice
0.38m
5.3m
Uncons. Ice
2.06m
27mm
278mm
20mm
Ridge 18
Full Scale Values
Target Model Scale Values
(at 1: 19.1 scale)
40 m
0.48m
Level Ice
Incr. Cons. Ice
1.14m
3.7m
Uncons. Ice
2.09m
24mm
194mm
60mm

Note: The average depths of consolidation and of unconsolidated material were determined by dividing the areas of these respective materials by the width of the ridge. As the sails of these ridges were noted to be consolidated *(Geisel et al, 1982)* the sail area has been included in the areas of consolidated material. See Comfort, 1988 for further information.

Figure 4.1 Representation of "Average" Ridge from Field Data

TABLE 4.1

INCREMENTAL PENETRATION ENERGY FOR POLAR STAR: FULL SCALE-MODEL SCALE COMPARISON FOR RIDGES 17 AND 18

	Ridge 17		Ridge 18	
	Consolidated Ice	Unconsolidated Ice	Consolidated Ice	Unconsolidated Ice
Reduction and Analysis of Model Test Data:				
Model Scale Thickness (mm) of Incremental Part of Field Ridge (see figure 4.1)	20	278	60	194
Unit Penetration Energy (J/m) of Incremental Ice for a Model Speed of 0.4 m/s. See Note.	40	240	150	140
Range of Speeds (m/s) in model scale units, which occurred in the field.	0.41 - 0.94		0.66 - 1.3	
Velocity-corrected range of model scale unit penetration energies (J/m) for above range of speeds.	40 - 70	240 (No correction applied)	190 - 320	140 (No correction applied)
Mid-range Predicted Incremental Penetration Energy for ridge (i.e., Unit penetration energy x Width of Ridge)	110	490	500	290
Total Model Scale Incr. Penetration Energy (J) for Cons. and Uncons. Ice	600		790	
Comparison of Model Scale And Full Scale Data:				
Total Field Incremental Energy (MJ) Predicted by Model Tests	80		105	
Measured Field Incremental Energy (MJ)	135		146	
Diff. Between Model Test and Field Data	-40%		-29%	

NOTE: The "unit penetration energy" was determined from the measured steady-state resistances in level ice and broken ice for the POLAR STAR. See figures 3.11 and 3.13. This was defined as the energy required for the ship to penetrate a unit distance, which has the units of J/m, as follows:

Unit Penet. Energy = Steady state resistance - open water resistance [4.1]

As a comparison of the incremental energies at model scale and full scale is being conducted, the open water resistance was subtracted from the steady-state resistance. (The open water resistance was considered to be included in the level ice component of the total ridge penetration energy.) For this comparison, the open water resistance was defined using the results of model tests at the IMD and at FTL's basin. As the open water resistance is small in relation to the ice resistance (i.e., typically less than 10% of the ice resistance), the results of this comparison are not sensitive to the open water resistance.

The incremental energies predicted by the model tests were compared to the measured field data. See table 4.1. The model test results underpredict the measured penetration energies by 30 to 40%.

One cause of this discrepancy was thought to be the relative densities of the model and full scale ice. The density of the model ice was significantly greater than that of full scale ice. This causes distortions in the model as the buoyancy forces acting on the model ice pieces may be significantly less (i.e., by a factor of 2) than the scaled full scale forces. This issue has been discussed in [9]. For proper scaling, of buoyancy forces, the following relationship should be respected:

$$\lambda_b = (\rho_w - \rho_i)/(\rho_{wm} - \rho_{im}) = 1 \qquad [4.2]$$

where: ρ_w = Density of seawater
ρ_i = Density of sea ice
ρ_{wm} = Density of water used in tank tests
ρ_{im} = Density of model ice

Typical values for the above parameters are 1020 Kg/m^3, 900 Kg/m^3, 1000 Kg/m^3, and 940 Kg/m^3, respectively. With these figures, the above relationship has a value of about 2. Thus, the buoyancy force acting on an ice piece in full scale will be about double that at model scale. For the rubble ice tests, buoyancy forces are one of the major forces acting on the ice blocks. Keinonen[10] has suggested a relationship for rubble ice resistance which indicates a linear dependence of resistance on density.

To investigate the potential effect of this discrepancy, the incremental penetration energies associated with the rubble ice for ridges 17 and 18 (as listed in table 4.1) have been "corrected" for density differences, as follows:

$$\begin{array}{c} \text{Corrected Incr.} \\ \text{Penet. Energy} \\ \text{for Rubble Ice} \end{array} = \begin{array}{c} \text{Pred. Incr. Penet.} \\ \text{Energy (as listed} \\ \text{table 4.1) for} \\ \text{Rubble Ice} \end{array} \times \frac{\rho_w - \rho_i}{\rho_{wm} - \rho_{im}} \qquad [4.3]$$

With the typical values for ρ_w, ρ_i, ρ_{wm}, and ρ_{im} that are listed above, this correction provides a good match (i.e., within 5%) between the field data and the model test results for both ridges. This issue is discussed further in section 5.4.

4.1.2 KIGORIAK: Prediction of Incremental Penetration Energy for Ridges 17 and 18 and Comparison to POLAR STAR

It is of interest to compare the predicted incremental penetration energies for the KIGORIAK and the POLAR STAR as these two ships have significantly different hull forms. Table 4.2 provides a prediction of the incremental penetration energy requirements for the KIGORIAK for ridges 17 and 18. This prediction is based on the test results obtained in this program and has been performed using the same approach that was used for the POLAR STAR. No corrections for distortions due to density differences have been applied.

The predicted incremental energies for the two ships have been compared on a "per-unit beam" basis, as summarized in Table 4.3. This preliminary comparison suggests that the POLAR STAR's hull form is more efficient for ridges 17 and 18 than the KIGORIAK's. However, since the total penetration energy is the sum of the level ice component and the incremental energy, more detailed comparisons need to be undertaken before general statements can be made. This has not been done as a detailed comparison of the POLAR STAR and KIGORIAK hull forms was beyond the scope of this study.

TABLE 4.2

PREDICTED INCREMENTAL PENETRATION ENERGY FOR KIGORIAK FOR RIDGES 17 AND 18

	Ridge 17		Ridge 18	
	Consolidated Ice	Unconsolidated Ice	Consolidated Ice	Unconsolidated Ice
Model Scale Thickness (mm) of Incr. Part of Field Ridge (See Fig 4.1)	17	236	51	165
Unit Penetr Energy (J/M) of Incr Ice for a Model Speed of 0.4 m/s	20	165	120	107
Range of Speeds (m/s), in model scale units, which occurred in the field	.38 - .87		.61 - 1.2	
Velocity-corrected range of model scale unit penet. energies (J/M) for above range of speeds.	20-35	165 (No correction applied)	160-240	107 (No correction applied)
Mid-range pred. penetr energy (J) for ridge (i.e., Unit penet. energy x ridge width)	44	290	340	190
Total Model Scale Incr. Penetr Energy (J) for Cons. and Uncons. Ice	334		530	
Total Predicted Incr Penetr Energy in full scale units (MJ)	86		136	

TABLE 4.3

COMPARISON OF POLAR STAR AND KIGORIAK FOR RIDGES 17 AND 18

	POLAR STAR		KIGORIAK	
Ridge	Pred. F.S. Incr Penet Energy (MJ)	Incr Penet Energy / Max Beam of Ship	Pred. F.S. Incr Penet Energy (MJ)	Incr Penet Energy / Max Beam of Ship
17	80	3.3 MJ/M	86	4.5 MJ/M
18	105	4.3 MJ/M	136	7.1 MJ/M

NOTE: The maximum waterline beams of the POLAR STAR and the KIGORIAK were taken as 24.4 m and 19.25 m, respectively.

4.2 POLAR STAR: Full Scale-Model Scale Comparison of Resistance vs Distance Curves for Selected Tests

The previous section has focussed on the magnitude of the incremental penetration energy as a basis of comparison for the model scale and full scale results. The form of the resistance vs distance curve is also important as it affects the travel distance over which energy is expended during single-pass ramming. This is important for assessing the possibility that the ship will be stopped, and forced to ram, by a given sequence and spacing of ridges.

The results of tests DS3-2 and DS3-8 have been analyzed in detail to investigate this issue. These tests were selected as they encompass both ice types. Also, the ice was relatively thick for both tests and was sufficient to closely model the incremental penetration energy for ridge 18.

This analysis has been performed for two ridge widths as there is some discrepancy between the field survey data and the field resistance vs distance data. As outlined in section 2.1, the resistance is expected to commence dropping after the bow has penetrated the ridge. Thus, the distance, on the resistance versus distance profile, between the points where the resistance starts to rise and subsequently starts to drop provides one method for assessing the ridge width that was "seen" by the ship. For ridge 18, this distance is about 46 m (i.e., 2.4 m at 1:19.1 scale). The measured width of ridge 18 was 40 m (i.e., 2.1 m at 1:19.1 scale). Analyses were performed for both of these ridge widths.

Figures 4.2 to 4.5 show the predicted results. Three plots are shown for each case, as follows:

(a) A plot of the mean resistance vs position curve measured during penetration of the ice edge, and a reproduction of this curve that has been shifted to the right by a distance equal to the ridge width.

(b) The predicted resistance vs distance curve for an ice slab that is equal in width to the ridge width. This was determined by numerically subtracting the "shifted" trace (see above) from the initial record (which was measured during the penetration of the ice edge).

(c) The cumulative work done as a function of the travel distance. This represents the area under the resistance vs distance curve for the "ridge" (i.e., plot (b) above).

The field data for ridge 18, expressed in model scale units, are also shown on figures 4.2 to 4.5.

The incremental penetration energies measured during these model tests are of the same general magnitude as the measured value for ridge 18, as shown in Table 4.4. It can be seen that, had model tests been conducted with slightly different thicknesses of sheet ice and broken ice, an exact match between the model scale and full scale penetration energies could have been obtained.

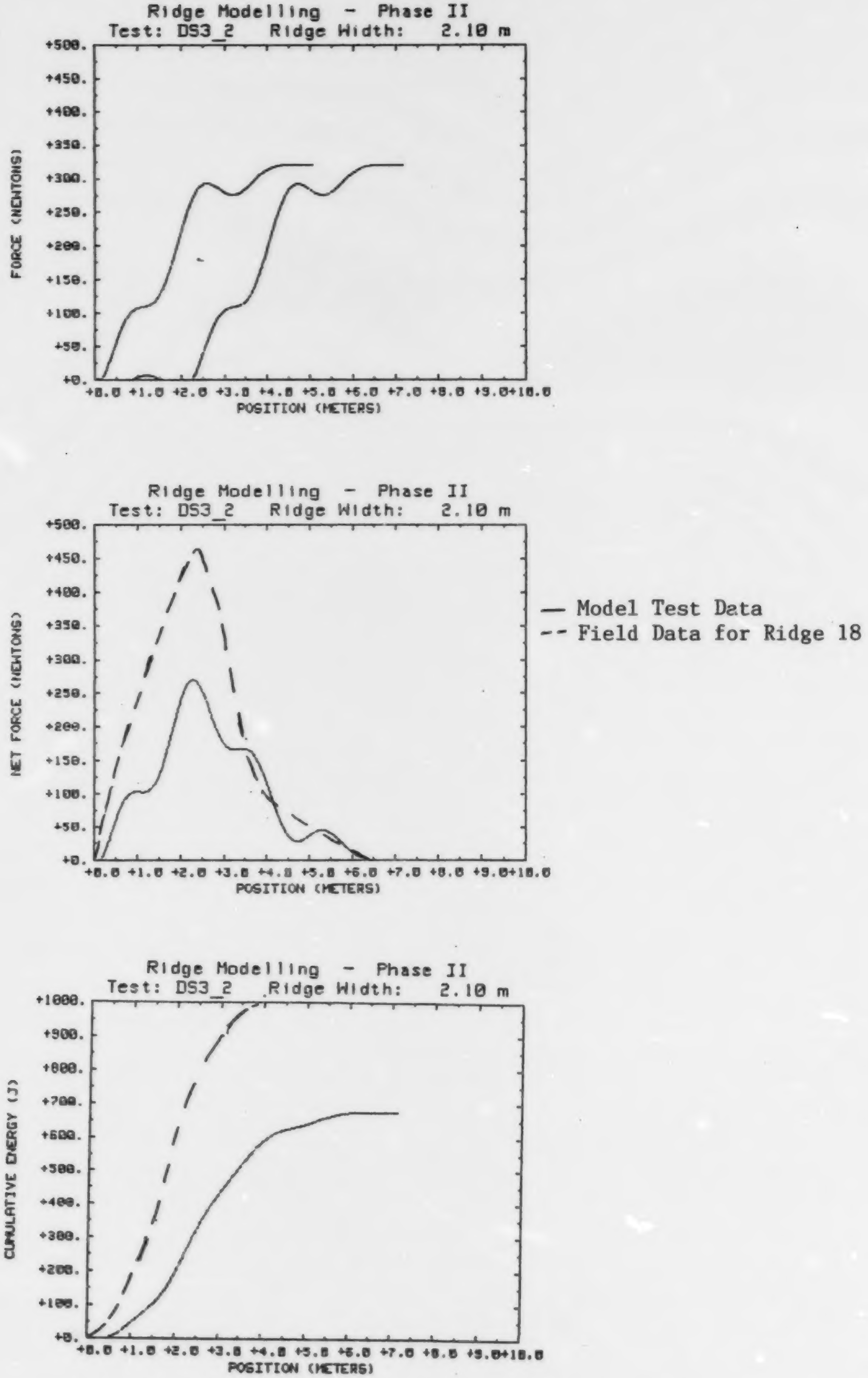
Figures 4.2 to 4.5 also compare the resistance vs distance curves obtained from the model tests with the field data. The travel distances affected by the ridge that are predicted by the model tests agree with the field data within about 15%.

From this limited calibration, it can be seen that the proposed approach to ridge modelling is capable of reproducing the form of the force vs distance curve that was measured in the field.

TABLE 4.4

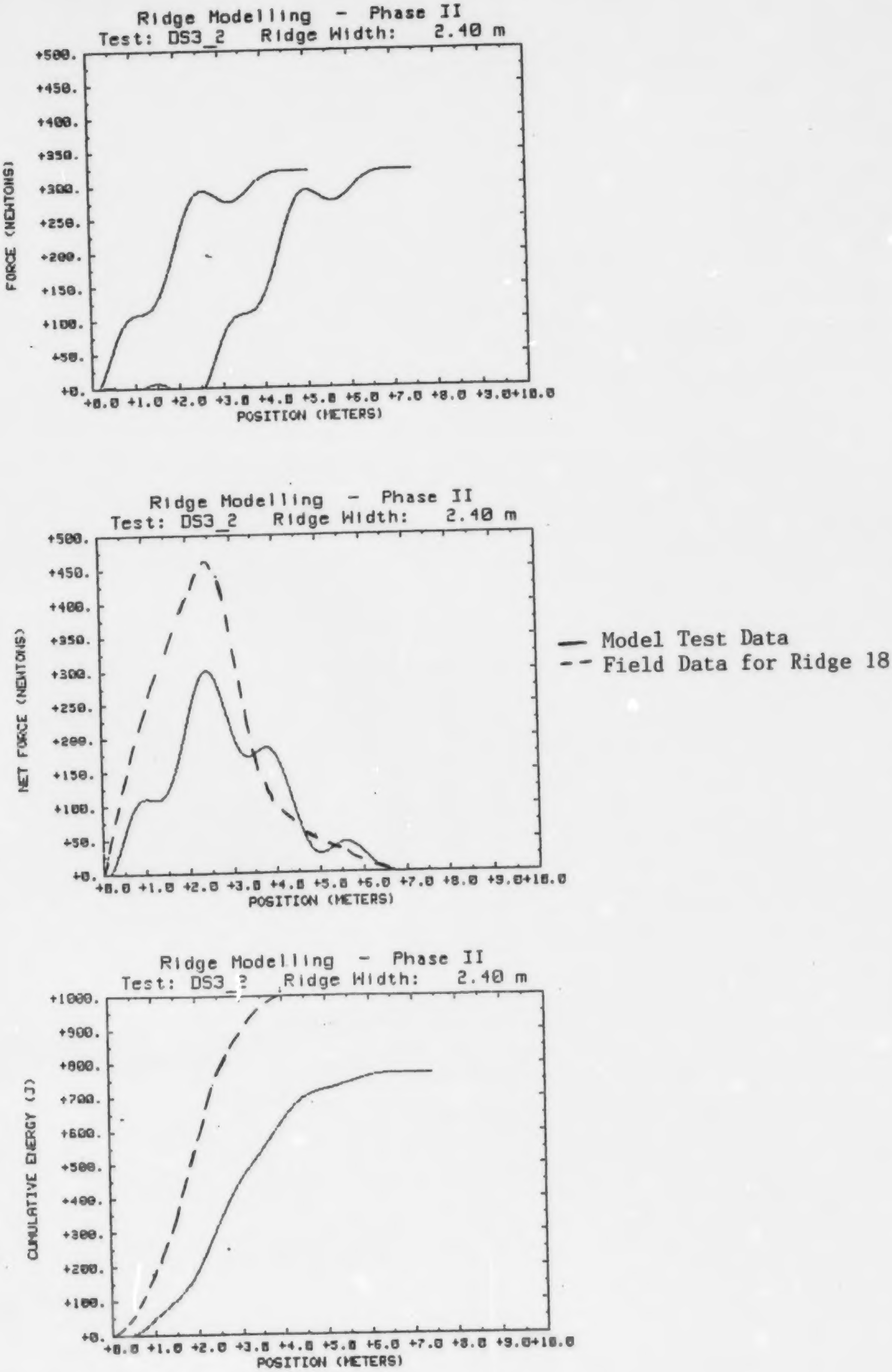
MODEL SCALE INCREMENTAL PENETRATION ENERGIES

Test #	Ice Type	Model Scale Ridge Width (m)	Model Scale Incr. Penet. Energy (J)	Difference Between Model Test Result and Field Data For Ridge 18
DS3-2	Sheet	2.1	680	-40%
DS3-2	Sheet	2.4	780	-30%
DS3-8	Broken	2.1	950	-16%
DS3-8	Broken	2.4	1100	- 3%



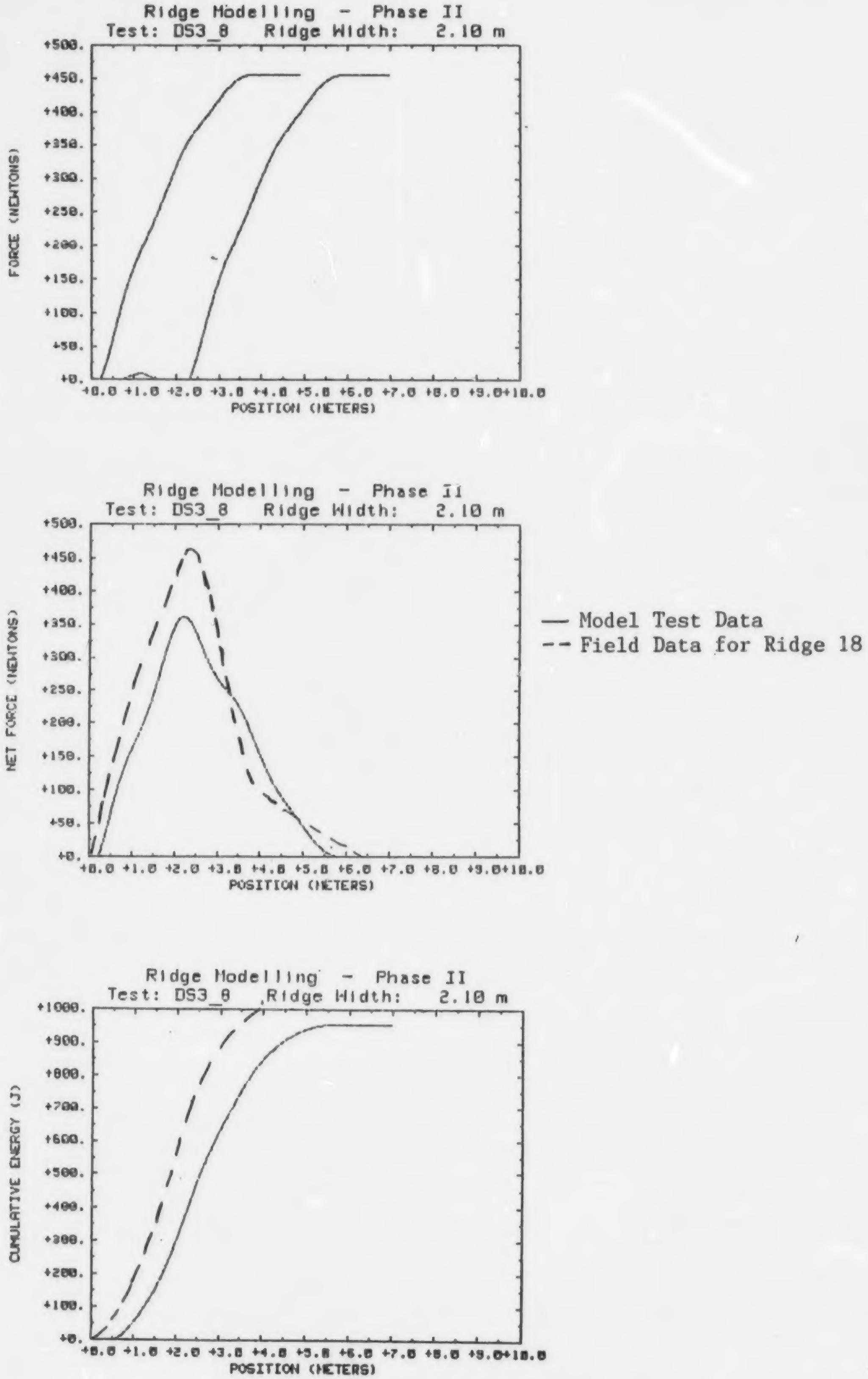
Reduced Data Record for Sample Test in Sheet Ice
with The Polar Star Model

Figure 4.2



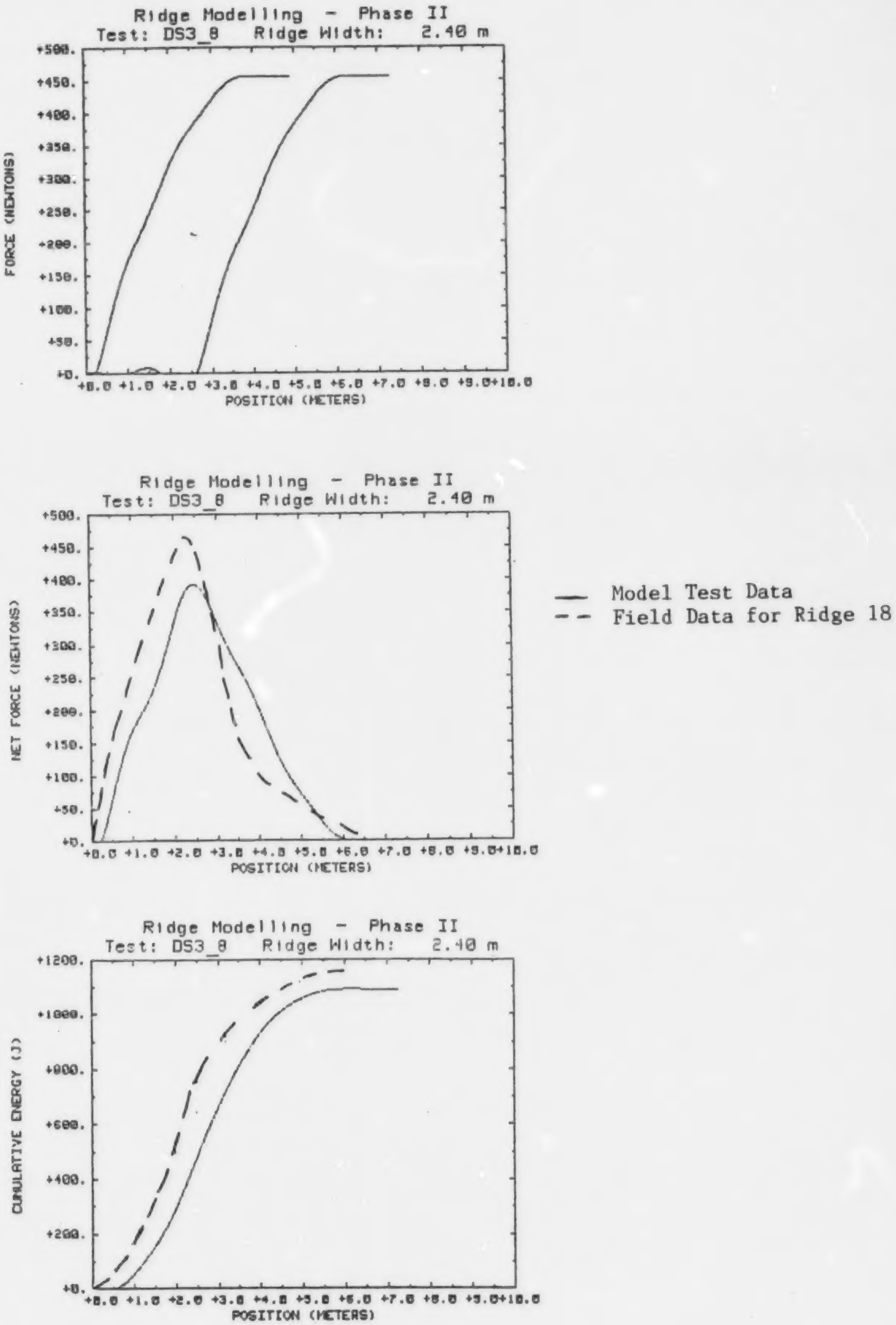
Reduced Data Record for Sample Test in Sheet Ice
with The Polar Star Model

Figure 4.3



Reduced Data Record for Sample Test in Rubble Ice
with The Polar Star Model

Figure 4.4



Reduced Data Record for Sample Test in Rubble Ice
with The Polar Star Model

Figure 4.5

5.0 NUMERICAL MODELLING OF SINGLE PASS RAMMING

5.1 Overview

This task was carried out to develop and exercise a simple computer-based numerical program for predicting full scale performance in first year ridges up to the vessel's limiting ridge capability and for predicting the size of the limiting ridge. The program provides a means for analyzing and interpreting the model test results and for performing transit analyses.

In order to minimize software development efforts, the model was developed on a commercially available spreadsheet program "shell", called EXCEL. Coefficients obtained from model scale (or full scale) tests in level ice and rubble ice are required as input for the program. The program can accommodate a range of level ice thicknesses and ridge consolidated and unconsolidated depths. The program predicts the ship's resistance and velocity as a function of travel distance for single-pass ramming events. The program can be set up to analyze any desired travel distance. However, the analysis of large travel distances increases the time required to execute the program.

The program, although not ship-specific, was calibrated based on the POLAR CLASS icebreakers for which full scale and model scale data in level ice and in ridges are available. It was run for both the POLAR STAR and the KIGORIAK with respect to ridges 17 and 18 and was used to predict the limiting ridge for each ship for a number of cases.

As only a limited budget was available to develop the model, it has a number of implications and limitations. Furthermore, it could only be run for a small number of operational cases. Both the POLAR STAR and the KIGORIAK were assumed to be operating at full power and the POLAR STAR was assumed to be operating in the diesel-electric mode. The algorithms used to predict level ice resistance are applicable for relatively weak ice (with a flexural strength of about 350 kPa full scale) and hence, the model's predictions are specific to this ice type. Therefore, general conclusions can not be made from these runs.

5.2 Ship Performance Inputs to the Model

The following aspects of ship performance need to be defined to run the model:

- level ice resistance
- rubble ice resistance
- resistance as a function of distance travelled during penetration into an edge of level ice and rubble ice.
- the relationship of ship thrust to velocity in open water.

The approaches used to define the above for the POLAR STAR and the KIGORIAK are described in the following sections.

5.2.1 Level Ice Resistance

Level ice resistance was predicted using a semi-empirical relationship developed for the TDC [11] with the following form:

$$R_i = C_o \rho_w g\ B\ h^2 + C_1\ \rho_w \cdot g^{0.5} B^{0.5}\ L\,V\,h \qquad [5.1]$$

Where:

R_i = Ice resistance (N)
C_o = Coefficient
C_1 = Coefficient
ρ_w = Water density (kg/m^3)
g = Gravitational constant (m/sec^2)
B = Ship beam (m)
h = Level ice thickness (m)
L = Ship length (m)
V = Ship velocity (m/sec)

The coefficients, C_o and C_1, were obtained for the POLAR STAR and the KIGORIAK as follows:

POLAR STAR: Model tests were carried out at the IMD ice tank in 1989 [7]. Full scale data were obtained during Arctic trials in 1982 in 0.3 to 0.5 m thick ice and during Antarctic trials in 1985 in 0.9 to 1.7 m thick ice. These field data were used [5] to develop the following semi-empirical predictor:

$$R_i = 3.60\, \rho_w g\ B\ h^2 + 0.20\ \rho_w \cdot g^{0.5} B^{0.5}\ L\,V\,h \qquad [5.2]$$

The coefficients, C_o and C_1, obtained from the model test results (for a flexural strength of 18.3 kPa and a friction factor of 0.1) are within 15% of full scale values. Table 5.1 and figure 5.1 show these results. Consequently, equation [5.2] was used to define the level ice resistance of the POLAR STAR.

KIGORIAK: The coefficients of the resistance equation were obtained from ice model tests carried out at IMD [8]. Table 5.2 summarizes these results. The model tests were carried out at a scale factor of 1:22.5. The flexural strength of the ice was 28.5 kPa (on average) which represents a full scale flexural strength of 641 kPa.

In order to compare the performance of the KIGORIAK with the POLAR STAR, the resistance data for the KIGORIAK model tests were corrected to an ice flexural strength of 15.6 kPa [8]. This strength corresponds to 350 kPa in full scale which was the target for the IMD's POLAR STAR model tests [7].

TABLE 5.1- POLAR CLASS MODEL TEST RESULTS (IMD TESTS)

TEST	ICE THICKNESS		VELOCITY		RESISTANCE		Co	CI	SHIP	CALC/
#	(mm)	(m)	(m/sec)		(N)	(MN)	3.6	0.2	RESIS.	MEAS.
IMD	MS	FS	MS	FS	MS	FS	A1	A2	(MN)	(-)
1	26	0.50	0.13	0.57	33	0.23	172550	68393	0.24	1.05
2	26	0.50	0.38	1.68	53	0.37	172550	202021	0.37	1.01
3	26	0.50	0.76	3.34	68	0.47	172550	401938	0.57	1.21
4	26	0.50	1.15	5.01	91	0.63	172550	602907	0.78	1.22
5	63	1.20	0.35	1.55	163	1.14	1013092	451269	1.46	1.29
6	63	1.20	0.71	3.08	214	1.49	1013092	898715	1.91	1.28
7	63	1.20	1.06	4.61	286	1.99	1013092	1344885	2.36	1.18
8	94	1.80	0.13	0.55	287	2.00	2255400	237755	2.49	1.25
9	94	1.80	0.37	1.61	431	3.00	2255400	699951	2.96	0.98
10	94	1.80	0.73	3.20	501	3.49	2255400	1392294	3.65	1.04
							AVERAGE			1.15
							STANDARD DEVIATION			0.12

FIGURE 5.1

POLAR STAR MODEL RESULTS & THEIR COMPARISON WITH THE FULL SCALE PREDICTION EQUATION

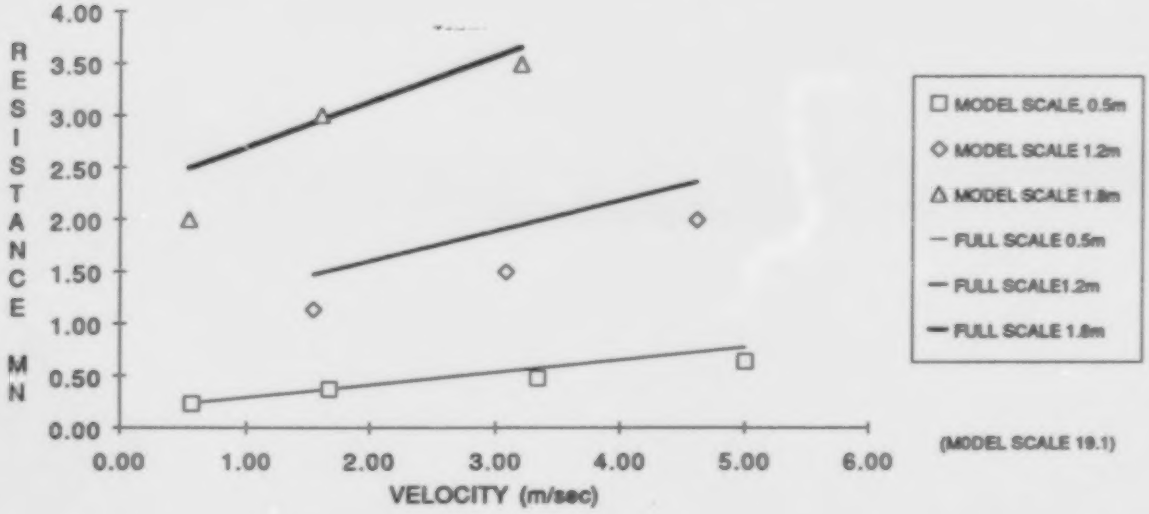


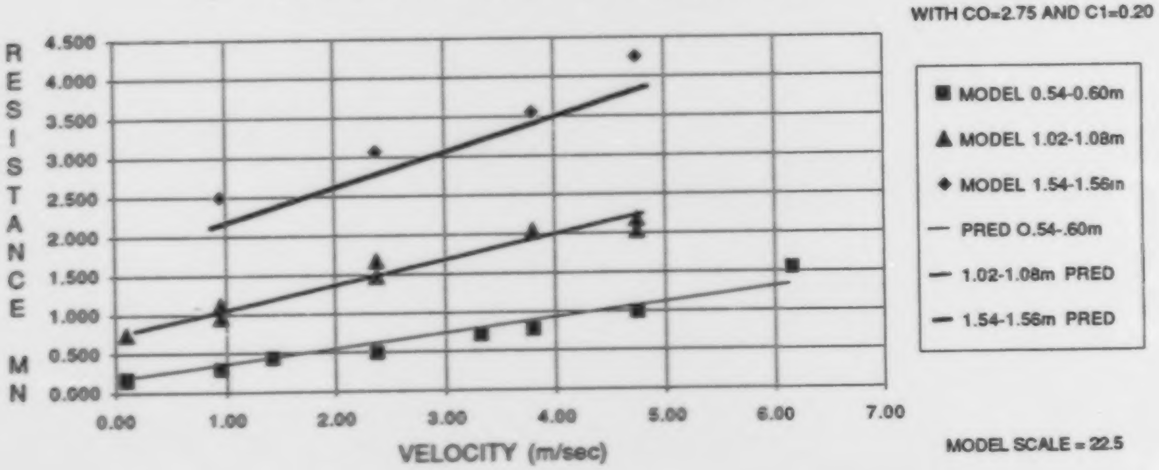
TABLE 5.2 - KIGORIAK MODEL TEST RESULTS (IMD TESTS)

TEST	ICE THICKNESS		VELOCITY		RESISTANCE *		Presawn RESISTANCE		RESISTANCE		RESISTANCE EQUAT. CONSTANTS		FULL SCALE SHIP RESIS.	RATIO OF Calc/ MEAS.
					28.5 kPa	641 kPa	0 kPa	0 kPa	15.6 kPa	350 kPa	Co 2.75	C2 0.20		
#	(mm)	(m)	(m/sec)		(N)	(MN)	(N)	(MN)	(N)	(MN)				
IMD	MS	FS	MS	FS	MS	FS	MS	FS	MS	FS	A	A2	(MN)	
1	30	0.66	0.50	2.37	51	0.581	35	0.399	44	0.498	235473	381600	0.617	1.24
2	29	0.66	1.00	4.74	99	1.128	72	0.820	87	0.988	232291	758025	0.990	1.00
3	29	0.66	0.80	3.79	78	0.888	56	0.638	68	0.775	230708	604350	0.835	1.08
4	28	0.63	0.20	0.95	33	~0.376	18	0.205	26	0.298	215176	145913	0.361	1.21
5	28	0.63	0.02	0.09	17	0.194	9	0.103	13	0.152	215176	14591	0.230	1.51
6	31	0.70	0.30	1.42	47	0.535	27	0.308	38	0.432	265085	242930	0.508	1.18
7	31	0.70	1.30	6.17	155	1.766	113	1.287	136	1.548	265085	1052697	1.318	0.85
8	30	0.68	0.70	3.32	75	0.854	49	0.558	63	0.720	246780	546916	0.794	1.10
9	29	0.65	0.02	0.09	19	0.216	11	0.125	15	0.175	225991	14954	0.241	1.38
10	81	1.82	0.20	0.95	319	3.634	101	1.150	220	2.506	1779664	419630	2.199	0.88
11	80	1.80	0.80	3.79	444	5.057	155	1.766	313	3.563	1740384	1659894	3.400	0.95
12	81	1.81	1.00	4.74	514	5.855	204	2.324	373	4.252	1753429	2082628	3.836	0.90
13	81	1.83	0.50	2.37	394	4.488	120	1.367	270	3.071	1788453	1051663	2.840	0.92
14	55	1.23	0.80	3.79	232	2.643	117	1.333	180	2.048	812564	1134192	1.947	0.95
15	55	1.24	0.50	2.37	200	2.278	84	0.957	147	1.678	815532	710163	1.526	0.91
16	55	1.25	0.20	0.95	140	1.595	49	0.558	99	1.124	830455	286652	1.117	0.99
17	54	1.22	1.00	4.74	243	2.768	130	1.481	192	2.184	800745	1407391	2.208	1.01
18	53	1.19	0.02	0.09	92	1.048	34	0.387	66	0.748	757195	27372	0.785	1.05
19	56	1.26	0.80	3.79	229	2.608	117	1.333	178	2.029	848540	1159028	2.008	0.99
20	55	1.23	0.50	2.37	168	1.914	84	0.957	130	1.479	812564	708870	1.521	1.03
21	56	1.27	0.20	0.95	113	1.287	49	0.558	84	0.956	860706	291827	1.15[illegible]	1.21
22	54	1.22	1.00	4.74	213	2.426	136	1.549	178	2.028	791937	1399630	2.192	1.08
											AVERAGE			1.06
											STANDARD DEVIATION			0.17

* RESISTANCE APPLICABLE TO THE FLEXURAL STRENGTH STATED (MODEL AND FULL SCALE)

FIGURE 5.2

KIGORIAK MODEL RESULTS & THEIR COMPARISON WITH THE RESISTANCE EQUATION



Using values of 2.75 and 0.20 for C_0 and C_1 respectively, a relatively good fit was obtained between the predicted resistances and the model test results (corrected for 15.6 kPa). See Table 5.2 and Figure 5.2. Consequently, the following equation was used to predict the level ice resistance of the KIGORIAK:

$$R_i = 2.75\,\rho_w g\; B\; h^2 + 0.20\,\rho_w \cdot g^{0.5} B^{0.5}\; L\, V\, h \qquad [5.3]$$

5.2.2 Rubble Ice Resistance

The rubble ice resistance of the POLAR STAR and the KIGORIAK was defined using model test results obtained during this study. The model scale resistance was related to the thickness as follows:

$$R_{rm} = C_m \,.\, (h_m)^{\alpha} \qquad [5.4]$$

Where:

R_{rm} = Model scale rubble ice resistance (N)
h_m = Model scale rubble ice thickness (mm)
C_m = Coefficient defined from the model test results
α = Exponent defined from the model test results

Values of 0.21 and 1.24 were obtained for C_m and α respectively for the POLAR STAR. For the KIGORIAK, respective values of 0.23 and 1.20 were obtained for C_m and α. (See section 3). As equation [5.4] is not dimensionally consistent, the full scale rubble ice resistance must be determined from the model test results as follows:

$$R_{rf} = C_m \,.\, [\,(\lambda^3/10^6)\,.\,(10^3/\lambda)^{\alpha}\,]\,.\, h_f^{\alpha} = C_f \,.\, h_f^{\alpha} \qquad [5.5]$$

Where:

λ = Scale factor
R_{rf} = Full scale rubble ice resistance (MN)
h_f = Full scale rubble ice thickness (m)
C_f = Coefficient for full scale prediction

Using equation [5.5], values of 0.20 and 0.25 were determined for C_f for the POLAR STAR and the KIGORIAK, respectively.

Equation [5.5] predicts that the rubble ice resistance is a function of the rubble ice thickness only. This form was used as the resistance was not significantly affected by the ship velocity over the range of speeds and rubble ice thicknesses tested during the model study. (See section 3). It is recommended that this approach be reviewed as more data become available to define rubble ice resistance.

As discussed in section 4.1, the buoyancy forces acting on an ice block are significantly less (i.e., by a factor of about 2) in the model basin than at full scale. This results from the fact that the refrigerated model ice has a relatively high density (in relation to sea ice in nature) and that the water in the tank is typically less dense than sea water (as fresh water is usually used during ice model tests). Data are not available to evaluate the effect of this distortion on rubble ice resistance. For this preliminary analysis, a density correction factor (F_d), has been introduced to predict full scale rubble ice resistance, as follows:

$$R_{rf} = F_d \, . \, C_f \, . \, h_f^{\alpha} = (\rho_w - \rho_i / \rho_{wm} - \rho_{im}) \; C_f \, h_f^{\alpha} \qquad [5.6]$$

For typical values, the density correction factor is equal to about 2 (see section 4). Thus, the values predicted by the model test results for rubble ice should be doubled to get the true full scale resistance. Most numerical model runs were made with the above correction for distortions due to density differences. However, two numerical model runs were made to investigate the effect of density distortions and are discussed in Section 5.4.

5.2.3 Resistance During Entry Into An Ice Edge.

Since no data were available in the literature prior to this test program, the model test results have been used directly in the numerical model. Table 5.3 and Figure 5.3 show the non-dimensional penetration values and their associated curves measured for the POLAR STAR and KIGORIAK models in rubble ice and sheet ice. An average curve was obtained for each of these cases and was input into the computer model.

FIGURE 5.3

NON DIMENSIONAL RESISTANCE VERSUS PENETRATION

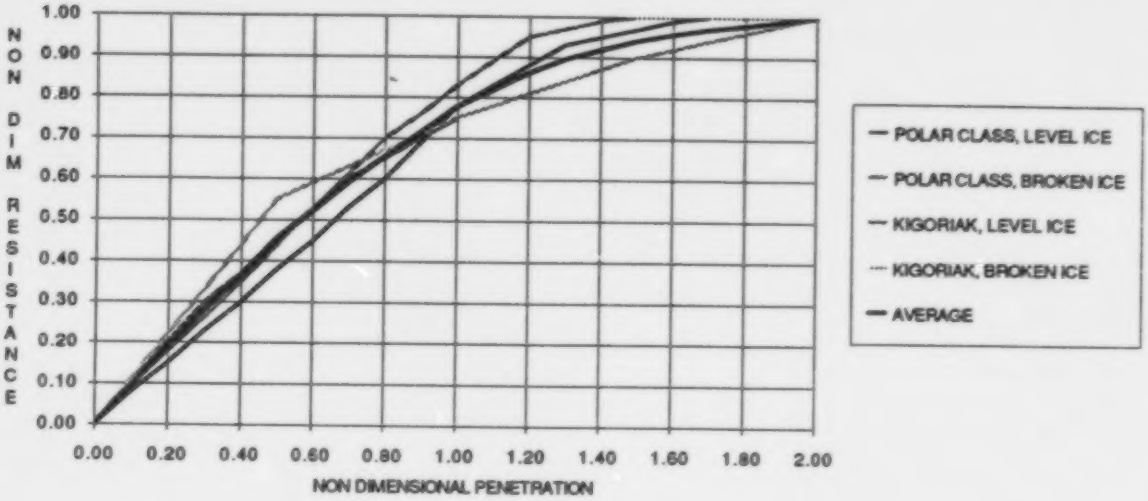


TABLE 5.3 - NON DIMENSIONAL PENETRATION VERSUS RESISTANCE

NONDIMENSIONAL PENETRATION	POLAR STAR		KIGORIAK		AVERAGE
	LEVEL ICE	BROKEN ICE	LEVEL ICE	BROKEN ICE	
0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.08	0.09	0.10	0.11	0.10
0.20	0.15	0.18	0.20	0.22	0.19
0.30	0.23	0.26	0.30	0.33	0.28
0.40	0.30	0.35	0.37	0.44	0.37
0.50	0.38	0.44	0.45	0.55	0.46
0.60	0.45	0.53	0.52	0.59	0.52
0.70	0.53	0.61	0.60	0.63	0.59
0.80	0.60	0.70	0.65	0.67	0.66
0.90	0.69	0.76	0.70	0.71	0.72
1.00	0.78	0.83	0.75	0.75	0.78
1.10	0.83	0.89	0.78	0.78	0.82
1.20	0.88	0.95	0.81	0.81	0.86
1.30	0.93	0.97	0.84	0.84	0.90
1.40	0.95	0.99	0.87	0.87	0.92
1.50	0.97	1.00	0.90	0.90	0.94
1.60	0.99	1.00	0.92	0.92	0.96
1.70	1.00	1.00	0.94	0.94	0.97
1.80	1.00	1.00	0.96	0.96	0.98
1.90	1.00	1.00	0.98	0.98	0.99
2.00	1.00	1.00	1.00	1.00	1.00

5.2.4 Total Ice Resistance During Single-Pass Ramming:

The total ice resistance was predicted as a function of travel distance using the method outlined in section 2.3 (which describes the ridge modelling approach) and illustrated in figure 5.4, as follows:

Case: Penetration distances up to the ridge width:

$$R_{TOTAL} = R_{LEVEL\ ICE} + R_{INCR} \cdot R_{ND} @ DND_{D} \qquad [5.7]$$

Case: Penetration distances greater than the ridge width:

$$R_{TOTAL} = R_{LEVEL\ ICE} + R_{INCR} \cdot [R_{ND} @ DND_{2} - R_{ND} @ DND_{1}] \qquad [5.8]$$

Where:

R_{TOTAL} = Total ice resistance

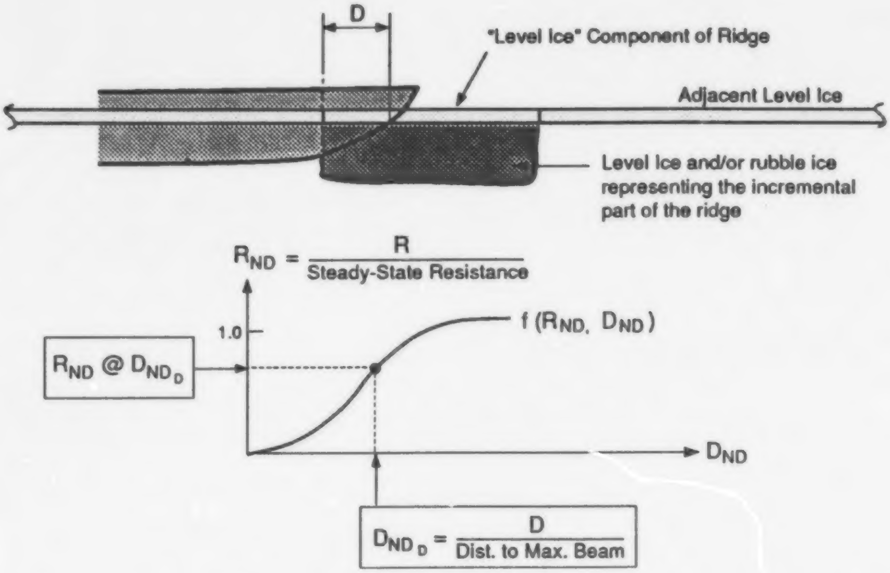
$R_{LEVEL\ ICE}$ = Resistance of level ice adjacent to the ridge

R_{INCR} = Resistance of level ice and/or rubble ice which represents the incremental part of the ridge (i.e. the part of the ridge which is in addition to its "level ice" component - see Figure 5.4). R_{INCR} denotes the resistance for full penetration of the ship.

$R_{ND}@DND_{1,2,3}$ = Non-dimensional resistance (R_{ND}) for non-dimensional penetration (D_{ND}) values corresponding to penetration distances of D, D_1 and D_2, respectively. The R_{ND} versus D_{ND} function was defined for the case where the ship enters an edge of level or rubble ice. See section 5.2.3.

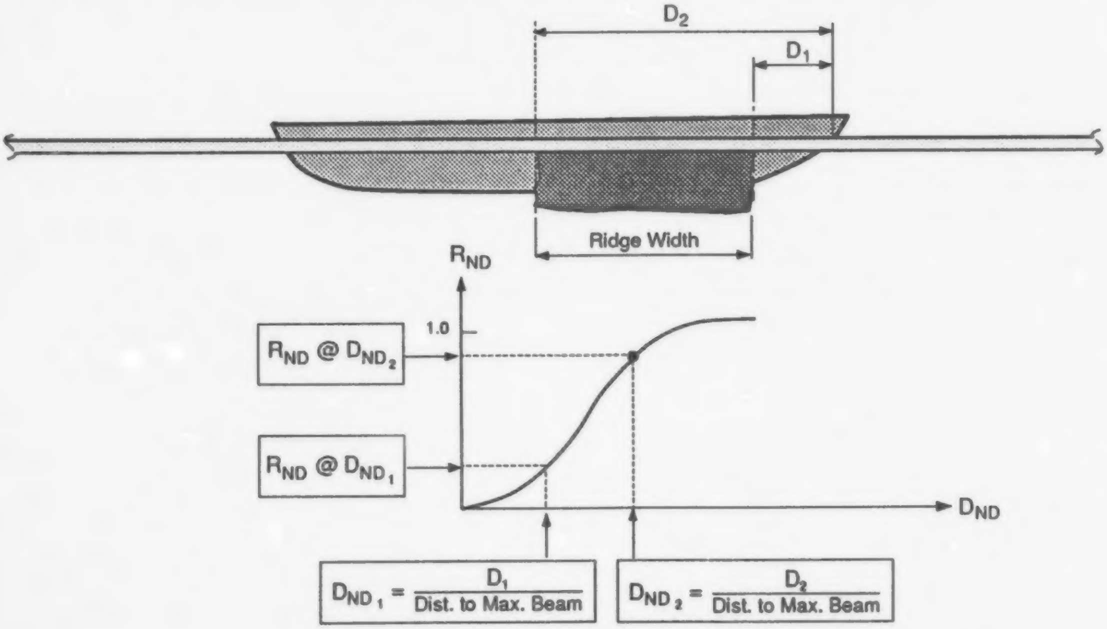
D, D_1, D_2 = Penetration distances as shown on figure 5.4.

Case: Penetration Up to the Ridge Width


D
"Level Ice" Component of Ridge
Adjacent Level Ice
Level ice and/or rubble ice representing the incremental part of the ridge
$R_{ND} = \frac{R}{\text{Steady-State Resistance}}$
1.0
$f(R_{ND}, D_{ND})$
R_{ND} @ D_{ND_D}
D_{ND}
$D_{ND_D} = \frac{D}{\text{Dist. to Max. Beam}}$

$$R_{TOTAL} = R_{LEVEL\ ICE} + R_{INCR} \cdot R_{ND} @ D_{ND_D}$$

Case: Penetration Greater than the Ridge Width


D_2
D_1
Ridge Width
R_{ND}
1.0
R_{ND} @ D_{ND_2}
R_{ND} @ D_{ND_1}
D_{ND}
$D_{ND_1} = \frac{D_1}{\text{Dist. to Max. Beam}}$
$D_{ND_2} = \frac{D_2}{\text{Dist. to Max. Beam}}$

$$R_{TOTAL} = R_{LEVEL\ ICE} + R_{INCR} \cdot [R_{ND} @ D_{ND_2} - R_{ND} @ D_{ND_1}]$$

Figure 5.4 Prediction of Ship Resistance During Ridge Transit

5.2.5 Thrust In Open Water Versus Ship Speed

POLAR STAR:

This relationship was established using the results of full scale tow rope tests [12] that were done while the ship was operating in the diesel-electric mode. For a power output of 13.4 MW(18,000 SHP), this relationship can be approximated by:

$$T_v = T_{o(max)} - 0.19\,V \qquad [5.9]$$

Where:

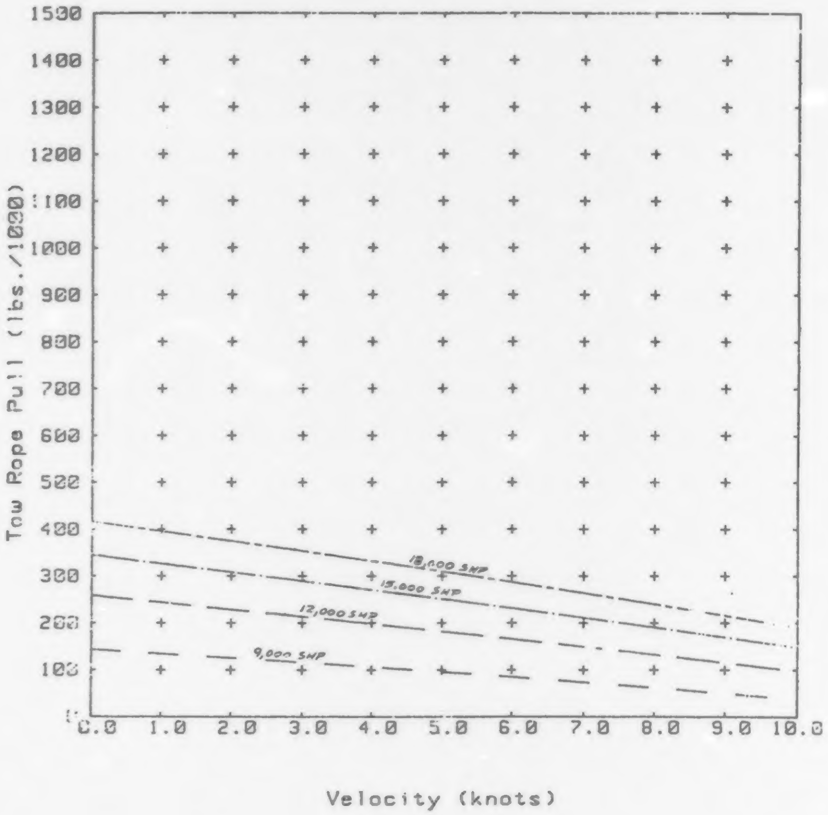
$T_{o(max)}$ = Bollard thrust produced at 13.4 MW output power (i.e. 1.86 MN)
T_v = Thrust at a specific ship speed (MN)
V = Ship velocity (m/sec)

As the ship may operate over a range of power levels, an algorithm was developed to predict the thrust versus speed relationship in relation to its power level. This was done using the available field data, which are summarized in figure 5.5. A relationship based on the ratio of the bollard thrusts at the power level of interest and at a power level of 13.4 MW was found to provide a reasonable fit to the data for power levels less than 13.4 MW. The following predictor was developed and input into the program:

$$T_v = T_o - [(T_o/1.86) . 0.19\,V)] \qquad [5.10]$$

Where:

T_o = Bollard thrust (MN) produced at the power level of interest.



TOW ROPE PULL vs. VELOCITY

(Equal Power 130 Rpm)

Figure 5.5 Polar Class: Field Tow Rope Pull Test Results

after [12]

KIGORIAK:

The same general approach described above for the POLAR STAR was used to predict the thrust versus speed relationship for the KIGORIAK. The results of full scale tests [13] are summarized in figure 5.6. For an output power of 12.2 MW, this relationship can be approximated by:

$$T_v = T_{o(max)} - 0.10\ V \qquad [5.11]$$

Where:

$T_{o(max)}$ =Bollard thrust at 12.2 MW output power (i.e. 1.80 MN)

The following algorithm was developed from an analysis of the field data to predict the thrust versus speed relationship over a range of power levels:

$$T_v = T_o - [(\ T_o\ /1.80)\ .\ 0.10\ V))] \qquad [5.12]$$

Where:

To = Bollard thrust (MN) produced at the power level of interest.

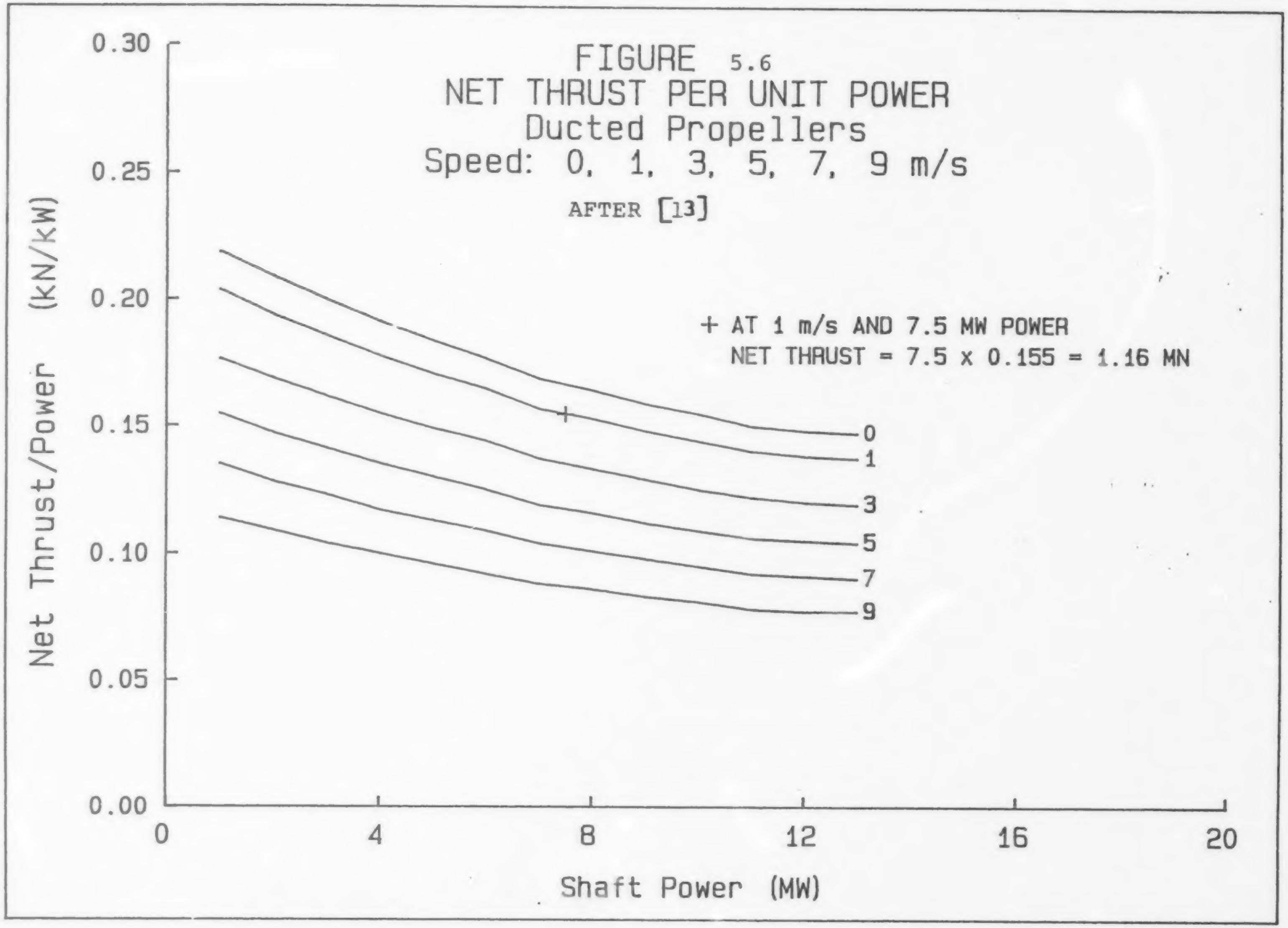


FIGURE 5.6
NET THRUST PER UNIT POWER
Ducted Propellers
Speed: 0, 1, 3, 5, 7, 9 m/s

AFTER [13]

5.3 The Numerical Ridge Penetration Model

5.3.1 Assumptions and Limitations:

The model was developed on the spreadsheet application program, EXCEL, (Version 2.2). The programmed spreadsheet is shown in table 5.4. The model was developed to provide a first order predictor of ship performance. As it was developed with less than 100 manhours, it has a number of assumptions, simplifications and limitations, including:

(a) The model is intended to be applicable for single-pass ramming only. Therefore, when the ship speed reaches a minimum value (which is an input defined by the operator with a default value of 0.01 m/sec), the program stops.

(b) The resistance equations are developed from data obtained from ice tests only. As the open water component of the total resistance is included in these expressions implicitly, an explicit expression for open water resistance was not introduced into the program. This causes computational problems for thin ice as the resistance becomes zero when the ice thickness is zero, which also predicts the open water resistance to be zero. To avoid this problem, the model should not be used for ice less than 0.5 meters thick.

(c) The resistance equations do not have an explicit dependence on ice-hull friction or ice strength. Hence, it should be remembered that the equations used are applicable to the cases which were used during testing in the ice tank (on which these equations are based).

(d) The added mass is assumed to be a constant factor of the ship displacement. The program has a default value of 9% of the ship's displacement for the added mass. This is an over-simplification of the effect of this factor especially in a transient process.

(e) The relationship of thrust in open water to speed was defined using empirical fits to available field data.

(f) No allowance for thrust deduction due to ice was incorporated into the model.

(g) The program is only intended to analyze "average" ridges (see figure 4.1) as opposed to actual profiles of field ridges.

5.3.2 User Inputs

User inputs are divided into three main sections, (i) ship characteristics, (ii)ice characteristics, (iii) coefficients from model scale results. These inputs are shown at the top left side corner of the spreadsheet (See table 5.4) and are entered into the appropriate cells by the user for each run.

TABLE 5.4

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

POLAR STAR ICEBREAKER

TYPICAL RIDGE
Level ice = 0.75 m

28-Jun-90

	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	25.45 (m)
9	LENGTH	107.29 (m)
10	DISTMAXBEAM	47.3 (m)
11	DISPLACEMENT	11020 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.85 (MN)
14	MAXIMUM THRUST	1.85 (MN)
15	STARTSPEED	5.00 (m/sec)
16	MINSPEED	0.01 (m/sec)

	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	0.75 (m)
20	RIDGE CONSDEPTH	1.00 (m)
21	RIDGE UNCONSDEPTH	3.00 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL	LEVEL ICE	CONSOLID	UNCONSO
(m)	(m)	(m)	(m)
0	0.8	0.8	0.8
20	0.8	0.8	0.8
20	0.8	1.8	3.8
60	0.8	1.8	3.8
60	0.8	0.8	0.8
1133	0.8	0.8	0.8

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	3.6 (-)
CONSTANT C1	0.2 (-)
RUBBLE ICE	
CONSTANT Cf	0.20 (-)
CONSTANT alfa	1.24 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26–28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	5.00	1.81	0.00	0.00	0.00	1.81	0.91	-0.08	4.92	5	1	71.22
31	4.92	1.79	0.00	0.00	0.00	1.79	0.92	-0.07	4.85	10	2	70.45
32	4.85	1.77	0.00	0.00	0.00	1.77	0.93	-0.07	4.78	15	3	69.71
33	4.78	1.76	0.00	0.00	0.00	1.76	0.95	-0.07	4.71	19	4	69.00
34	4.71	1.74	0.00	0.00	0.00	1.74	0.96	-0.06	4.65	24	5	68.31
35	4.65	1.72	0.00	0.00	0.00	1.72	0.97	-0.06	4.59	29	6	67.65
36	4.59	1.71	0.10	0.24	0.15	2.09	0.98	-0.09	4.49	33	7	82.19
37	4.49	1.68	0.19	0.46	0.29	2.44	1.00	-0.12	4.38	37	8	95.78
38	4.38	1.65	0.28	0.68	0.44	2.77	1.02	-0.15	4.23	42	9	108.77
39	4.23	1.61	0.37	0.87	0.57	3.05	1.05	-0.17	4.06	46	10	119.90
40	4.06	1.57	0.46	1.06	0.71	3.34	1.08	-0.19	3.88	50	11	131.11
41	3.88	1.52	0.52	1.18	0.82	3.52	1.12	-0.20	3.68	53	12	138.17

(i) Ship Characteristics:

The required input data are:

- the maximum waterline beam
- the waterline length
- the waterline distance between the bow and the point of maximum beam.
- the ship's displacement and added mass
- the ship's thrust at the bollard condition
- the initial speed of the ship.
- the "minimum" speed. This input is necessary as the program is intended to be only applicable to single-pass ramming. The "minimum" speed defines the speed at which the ship is considered to be stopped. A "FALSE" statement is printed in the program's spreadsheet when the "minimum" speed is reached.

(ii) Ice Characteristics:

The required input data are:

- ice thickness
- the thickness of the ridge's "extra" consolidation. This is defined as the thickness of the total depth of consolidation minus the level ice thickness.
- the thickness of the ridge's unconsolidated layer.
- the ridge width.
- the distance between the ship's bow and the ridge. The ship may not travel at steady-state for the initial conditions (i.e. ship speed, thrust, level ice thickness) that are selected by the user as inputs. Therefore, to find the steady-state speed, it is advisable to "start" the ship in level ice at least 100 metres away from the ridge. When the steady state speed is known, the program should be restarted with 20 metres distance between the ship's bow and the ridge to ensure a steady-state speed before contacting the ridge.

(iii) Coefficients from Model Scale Results:

The required input data are:

- the resistance equation coefficients (i.e. C_0 and C_1 for level ice and C_f and a for rubble ice). See Section 5.2.1 and 5.2.2 for further description of these coefficients.
- the densities of model scale ice, full scale ice, sea water and the water used in model tests. These parameters are important since model scale data are used to define the full scale rubble ice resistance.

Section 5.2 describes other ship inputs. These include the form of the equations to define level ice and rubble ice resistance, the resistance versus distance function for the entrance and exit phases, and the shaft thrust versus ship speed relation. These are hard-coded into the model and can be altered only by entering the appropriate spreadsheet cells.

5.3.3 Calculation Method

Figure 5.7 shows the flow chart for the model. Its calculation steps (as shown in the bottom half of table 5.4) are as follows:

1. Ship Starting Speed: (Column 1)

The ship starting speed is the speed of the vessel at the start of each time step (which is one second). The first value is an input (which is taken from the ship characteristics input file) while the following rows are calculated based on the starting velocity and the predicted acceleration.

2. Calculated Level Ice Resistance: (Column 2)

The level ice resistance is calculated from the equations described in section 5.2.2. The ice thickness is assumed to be constant for each portion (e.g., level ice, ridge) of the simulated travel distance.

3. Ridge Penetration Function: (Column 3)

This column lists the values of the non-dimensional resistance. The relationship of non-dimensional resistance to non-dimensional penetration is described in section 5.2.3 for the case where the ship enters an ice edge. That relationship is incorporated in the model as a lookup table which is shown in the top right portion of table 5.4.

4. Calculated Ridge Consolidated Resistance: (Column 4)

This column is determined by multiplying column 3 with the level ice resistance predicted by equation[5.1].

5. Calculated Ridge Unconsolidated Resistance: (Column 5)

This column is determined by multiplying column 3 with the rubble ice resistance predicted by equation [5.5].

6. Total Ice Resistance: (Column 6)

The total resistance, R_t, is determined by summing columns 2, 4 and 5.

7. Ship Thrust: (Column 7)

The shaft thrust, T, is calculated from the shaft thrust equation (see section 5.2.5), which relates shaft thrust to ship speed.

8. Acceleration: Column 8)

The acceleration of the vessel, a, is calculated from the following equation.

$$a = dv/dt = (T_n - R_t)/M \qquad [5.12]$$

where M is the total of the ship displacement plus the added mass.

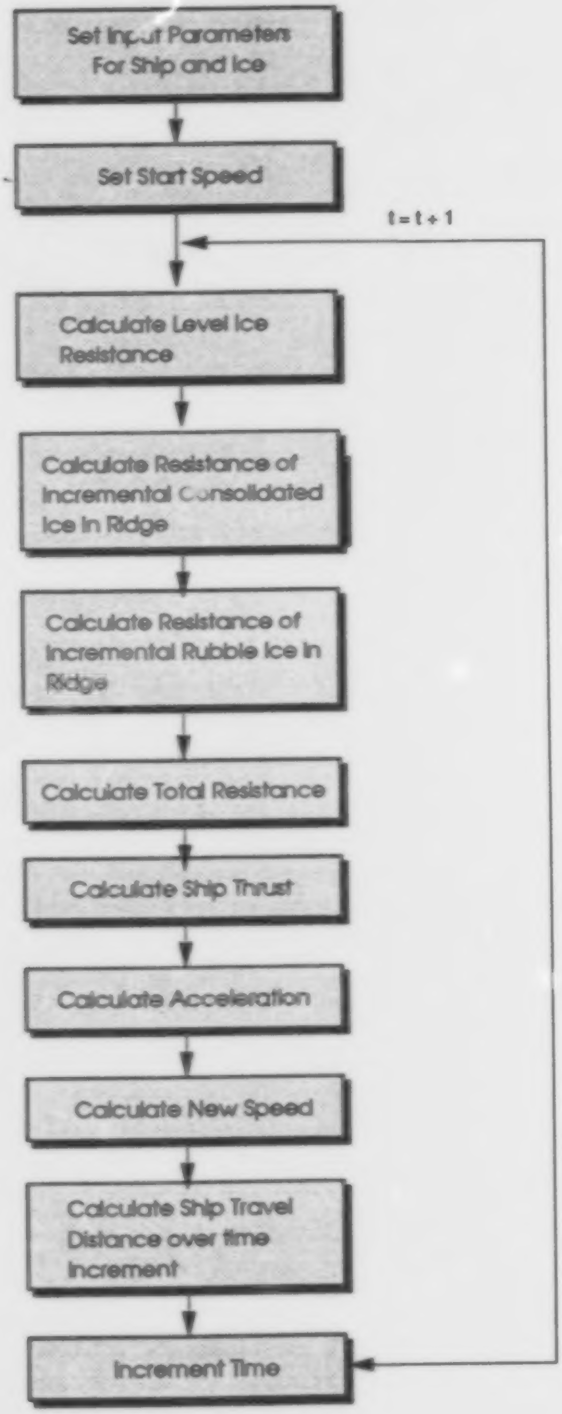

Set Input Parameters For Ship and Ice
Set Start Speed
t = t + 1
Calculate Level Ice Resistance
Calculate Resistance of Incremental Consolidated Ice in Ridge
Calculate Resistance of Incremental Rubble Ice in Ridge
Calculate Total Resistance
Calculate Ship Thrust
Calculate Acceleration
Calculate New Speed
Calculate Ship Travel Distance over time Increment
Increment Time

Figure 5.7 Numerical Model Flow Chart

9. Ship Travel Distance per Time Step: (Column 9)

The travel distance is calculated based on the starting velocity of the ship and the predicted acceleration for the time step.

10. Cumulative Ship Travel Distance: (Column 10)

The cumulative travel distance is equal to the sum of the previous cumulative travel distance and the travel distance predicted in step 9 for the time step.

11. Time: (Column 11)

The time unit is one second per step.

12. Resistance per Unit Width: (Column 12)

The total resistance calculated in column 6 is divided by the ship beam.

5.3.3 Graphical Output

Graphical output capabilities are built into the EXCEL program. This allows the user to design the graphical output (e.g., scales) as desired. To facilitate graphical output, this program has a built-in preformat that is automatically linked with the spreadsheet. Graphical output is set automatically to best fit the data being drawn.

5.4 Results of Numerical Model Runs

5.4.1 POLAR STAR: Comparison with Field Data for Ridges 17 and 18

The model was first run to predict the transit of ridges 17 and 18 by the POLAR STAR. For these runs, ridges 17 and 18 were simplified to the "average" ridges shown in figure 4.1. Figures 5.8 and 5.9 show the predicted resistance and velocity vs travel distance curves for ridge 17 and 18, respectively. Figures 5.10 and 5.11 compare the predicted curves with the field data for ridge 17 and 18, respectively.

Tables K.1 and K.2, in appendix K, provide a complete listing of these spreadsheet results. Figures 5.10 and 5.11 show the results of runs made with and without corrections for rubble ice resistance due to distortions in buoyancy forces resulting from density differences between model scale and full scale ice. The ship performance is predicted to vary greatly for these two cases. This is especially true for ridge 17 (see figure 5.10). This ridge was comprised of a relatively large proportion of rubble ice in comparison to ridge 18. As corrections for density differences have been only applied to rubble ice resistance, this causes the predicted ship performance to be more sensitive to this correction for ridge 17 than for ridge 18.

The numerical model provides a good prediction of the form of the curves measured in the field. However, the predicted resistance values are much lower than the resistances measured in the field. As discussed previously [1], the pre-ridge resistances measured in the field are significantly higher (by 1.2 MN, on average) than other field measurements of the level ice resistance of the POLAR STAR. This discrepancy introduces uncertainties regarding an appropriate basis of comparison for the predicted and measured resistances. For this study, this discrepancy has been interpreted as a bias in the measured field resistances. Consequently, for this preliminary comparison, the resistances measured in the field have been "corrected" by subtracting the observed bias (between the measured pre-ridge and level ice resistances) from the measured field resistance. The "corrected" field resistance vs distance curve for ridges 17 and 18 is also shown on figures 5.10 and 5.11. As a result of this correction, the predicted resistance and velocity curves match the field data quite well.

In view of this agreement between the results of the numerical model and the field data, it was decided to:

(a) utilize the "density correction" approach for predicting rubble ice resistance during subsequent model runs to predict the size of the "limiting" ridge, and for subsequent numerical model/full scale comparisons.

(b) utilize the "corrected" field resistances as a basis for subsequent numerical model/full scale comparisons.

The minimum speeds and peak resistances predicted by the model have been compared with the field data in Table 5.5. The model predicts minimum speeds that are about 10% less than those measured in the field for ridges 17 and 18. The peak resistances predicted by the model are within 5% of the "corrected"resistances measured in the field.

Figure 5.8

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

POLAR STAR: RIDGE 17

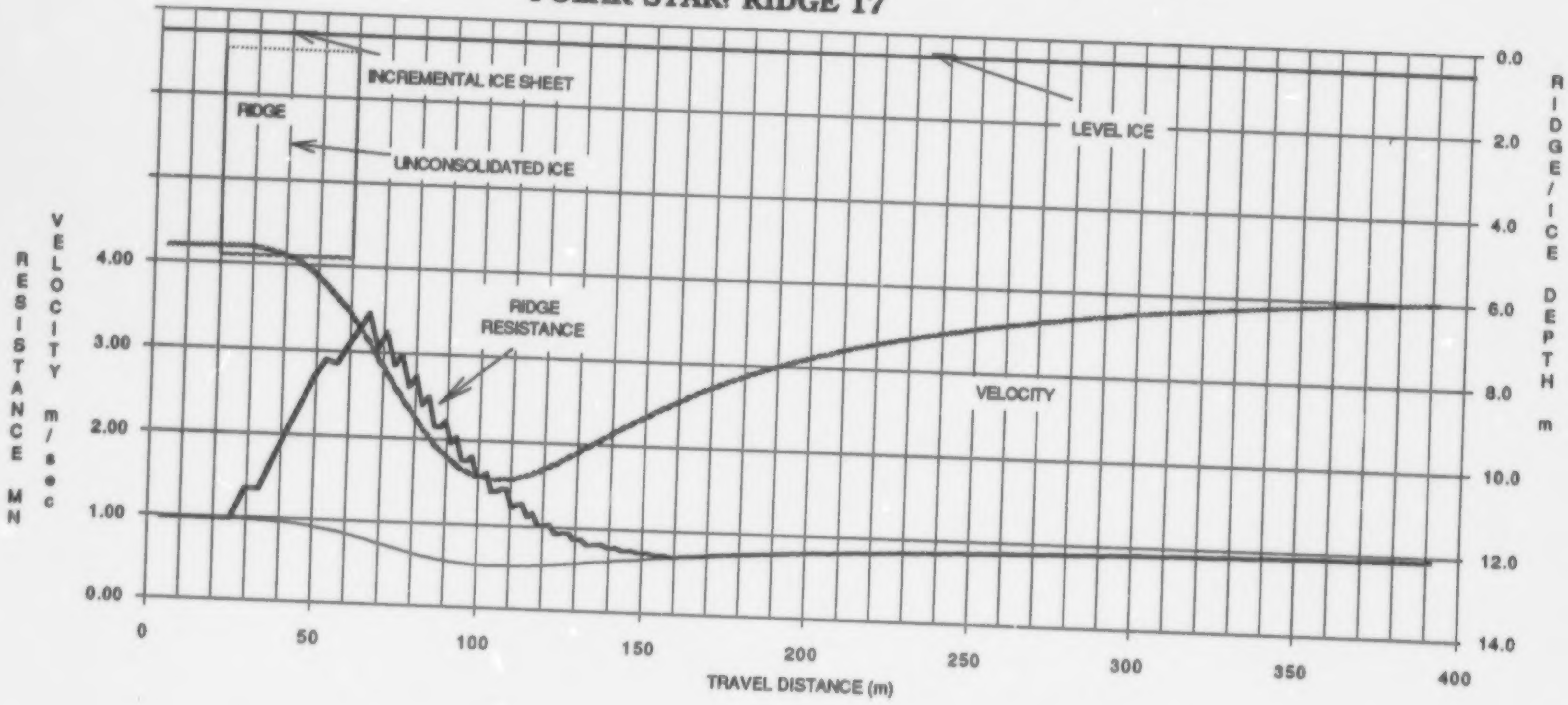
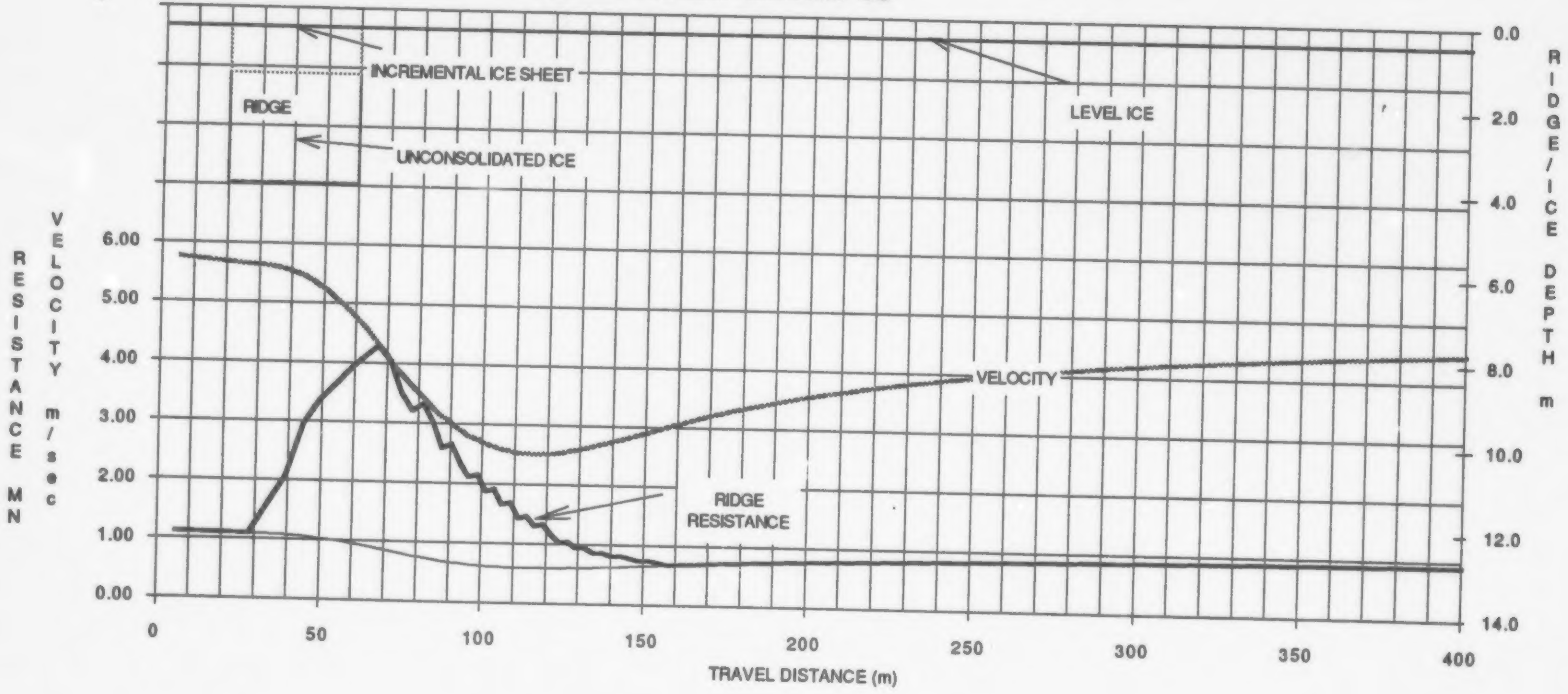
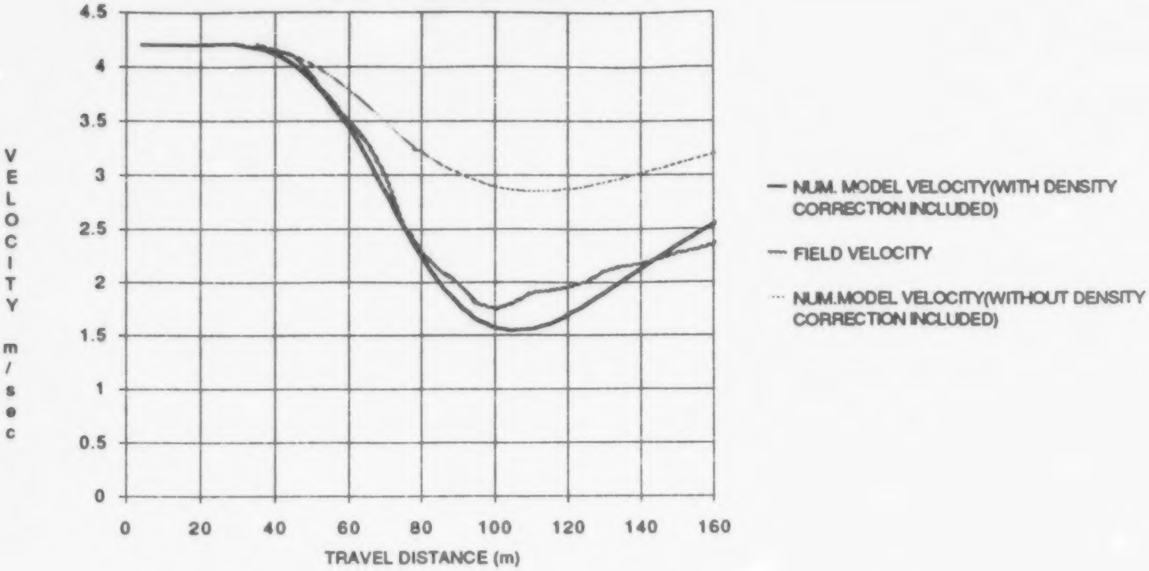


Figure 5.9

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

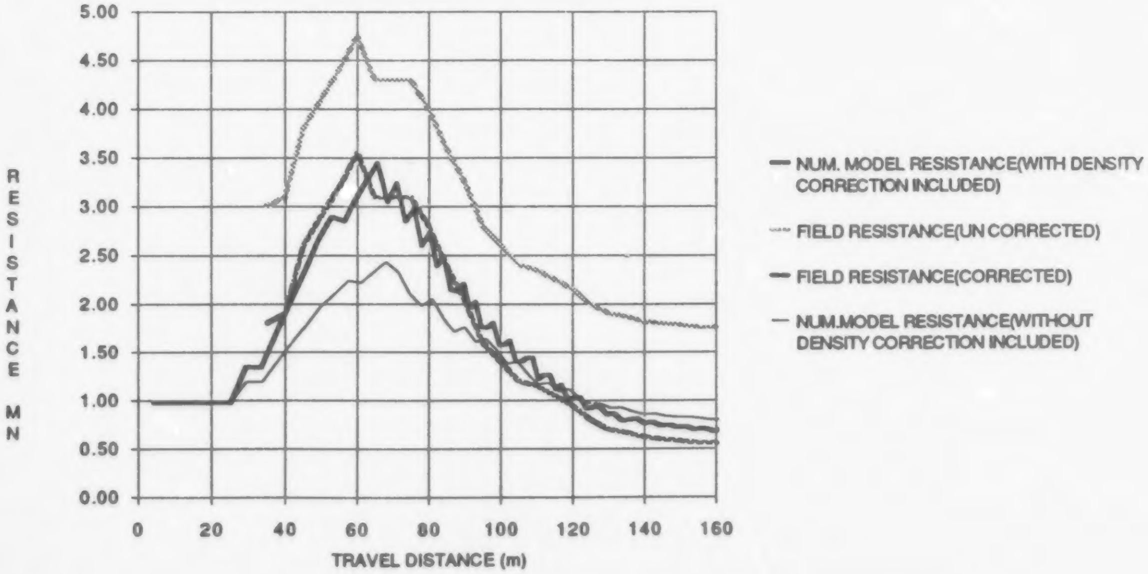
POLAR STAR: RIDGE 18





a - VELOCITY VS TRAVEL DISTANCE WITH AND WITHOUT CORRECTION FOR MODEL ICE DENSITY

POLAR STAR RIDGE 17



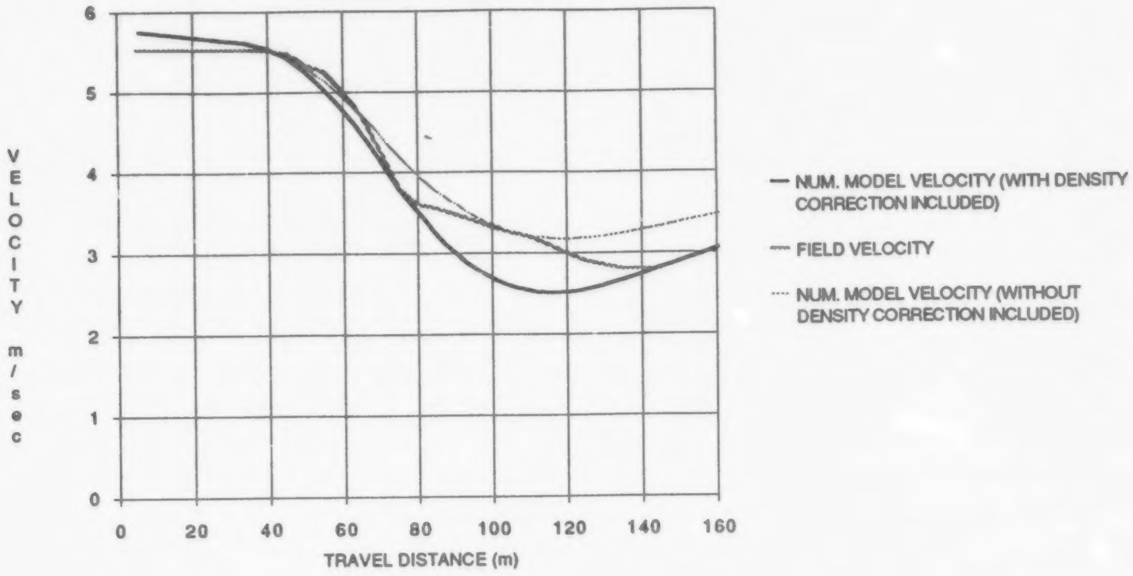
b - RESISTANCE VS TRAVEL DISTANCE WITH AND WITHOUT CORRECTION FOR MODEL ICE DENSITY

POLAR STAR RIDGE 17

Figure 5.10

a - VELOCITY VS TRAVEL DISTANCE WITH AND WITHOUT CORRECTION FOR MODEL ICE DENSITY

POLAR STAR RIDGE 18



b - RESISTANCE VS TRAVEL DISTANCE WITH AND WITHOUT CORRECTION FOR MODEL ICE DENSITY

POLAR STAR: RIDGE 18

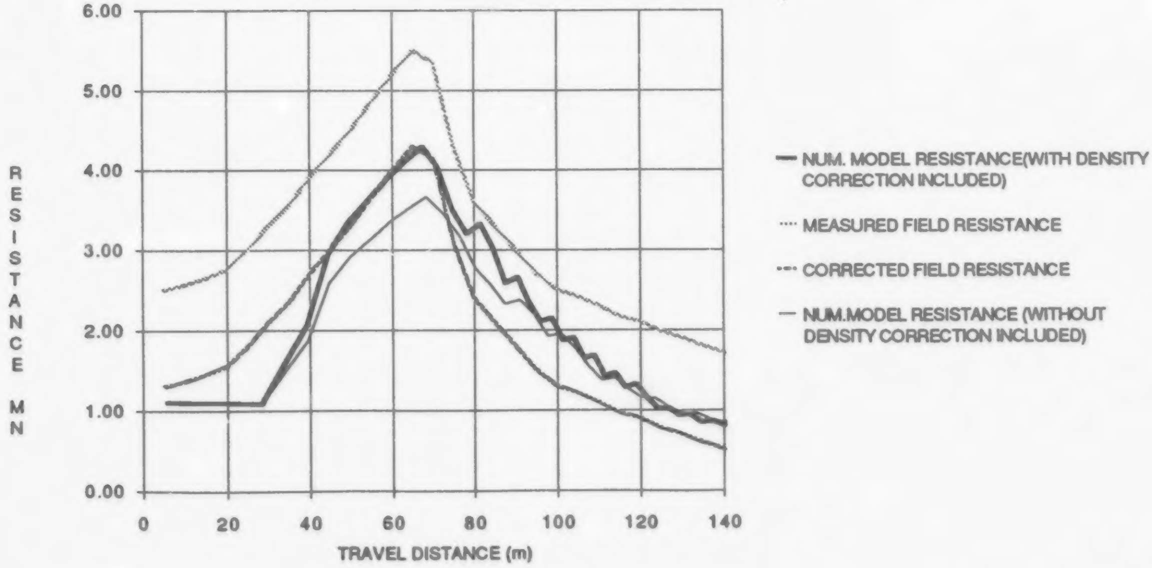


Figure 5.11

Table 5.5

Comparison of Measured and Predicted Minimum Speeds and Peak Resistances:

Minimum Speed Comparison:

	Ridge 17		Ridge 18	
	Field Data	Predicted Value	Field Data	Predicted Value
Minimum Speed (m/s) during ramming event	1.75	1.60	2.85	2.50

Peak Resistance Comparison:

	Ridge 17	Ridge 18
Field Data:		
Maximum Resistance (MN) During Ramming Event	4.75	5.50
Discrepancy (MN) between measured pre-ridge Resistance and Level Ice Resistance Predicted by Equation [5.2].	1.20	1.20
"Corrected" Maximum Resistance (MN) During Ramming Event	3.55	4.30
Numerical Model Predictions:		
Maximum Resistance (MN) During Ramming Event	3.50	4.30

5.4.2 Prediction of KIGORIAK's Performance in Ridges 17 and 18

Figures 5.12 and 5.13 and Tables K.3 and K.4, in appendix K, show the predicted performance of the KIGORIAK for ridges 17 and 18, respectively. For these runs, ridges 17 and 18 were simplified to the "average" ridges shown in figure 4.1.

The values of the ship input parameters used for these runs were as follows:

- Ship beam: 18.25 m [This is the average of the KIGORIAK's beam behind the reamers (i.e., 17.25 m) and at the reamers (i.e., 19.25 m).]
- Ship length: 84.40 m
- Ship displacement: 6550 tonnes
- Added mass: 9%
- Bollard thrust: 1.80 MN. This value was selected to be close to those used for the POLAR STAR (1.74 and 1.85 MN respectively for ridge 17 and 18). At this thrust, the KIGORIAK is predicted to travel steadily at speeds of 7.5 and 8.0 m/sec in 0.51 m and 0.46 m thick ice respectively. These are the measured thicknesses of the level ice adjacent to ridges 17 and 18, respectively.
- Level ice resistance coefficients (i.e. C_0 and C_1); 2.75 and 0.20 respectively
- Rubble ice resistance coefficients (i.e. C_f and a); 0.25 and 1.20 respectively
- Distance from bow to point of maximum beam: 25.3 m
- Minimum speed before the program stops: 0.01 m/s

The KIGORIAK is predicted to reach a minimum speed of 4.8 m/sec and 4.9 m/sec during its transit of ridges 17 and 18, respectively. The peak resistance is predicted to be 4.2 MN and 4.8 MN for ridges 17 and 18, respectively.

FIGURE 5.12

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

KIGORIAK: RIDGE 17

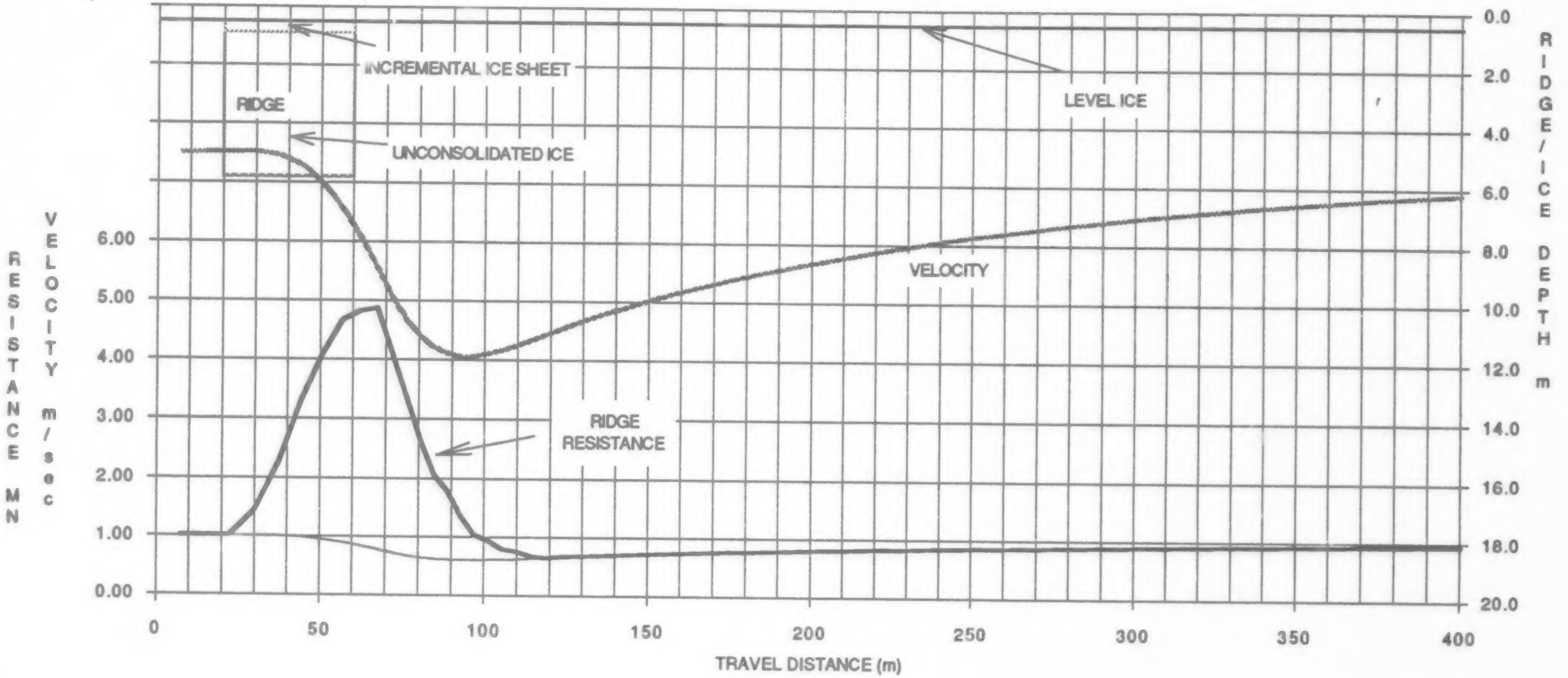


FIGURE 5.13

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

KIGORIAK: RIDGE 18

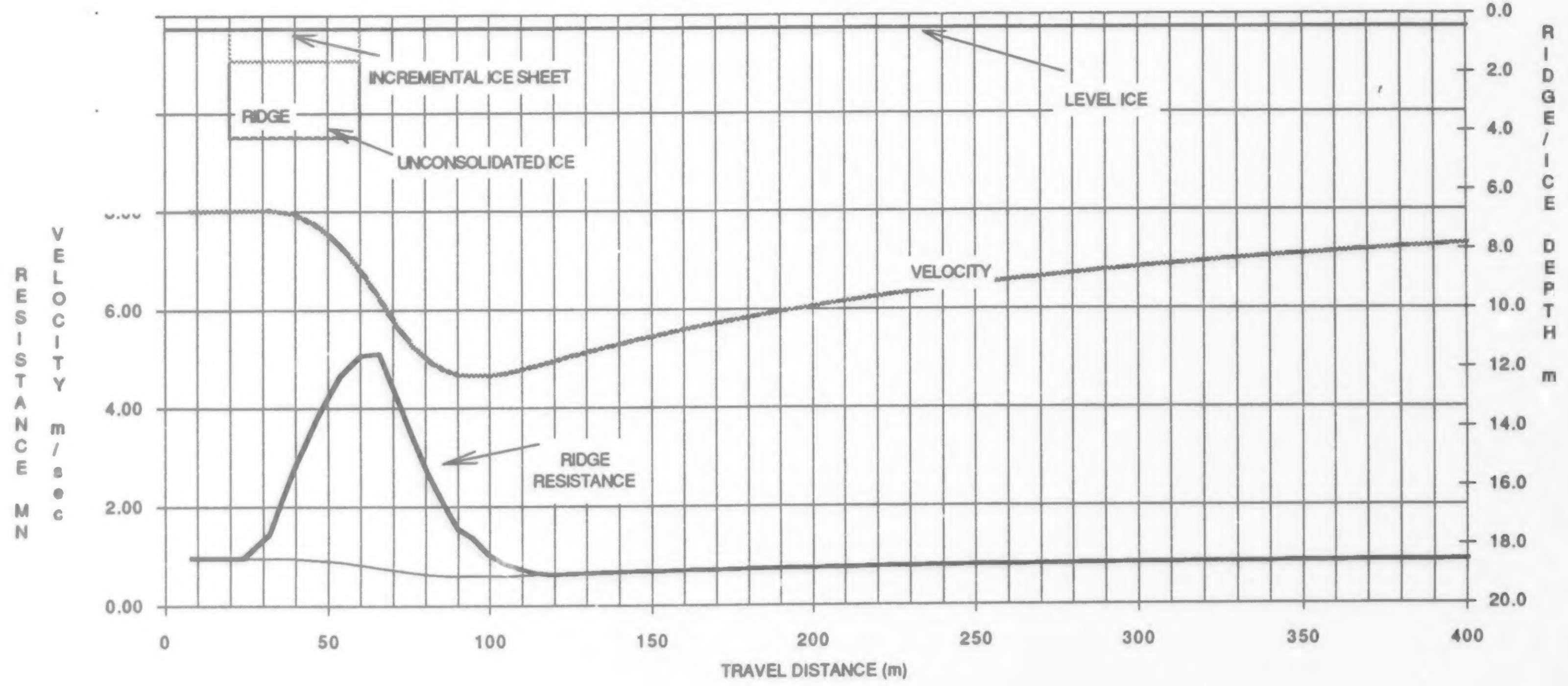


FIGURE 5.14

POLAR STAR & KIGORIAK COMPARISON(RIDGE 17)

(BOLLARD THRUST HELD EQUAL @1.8MN FOR BOTH SHIPS)

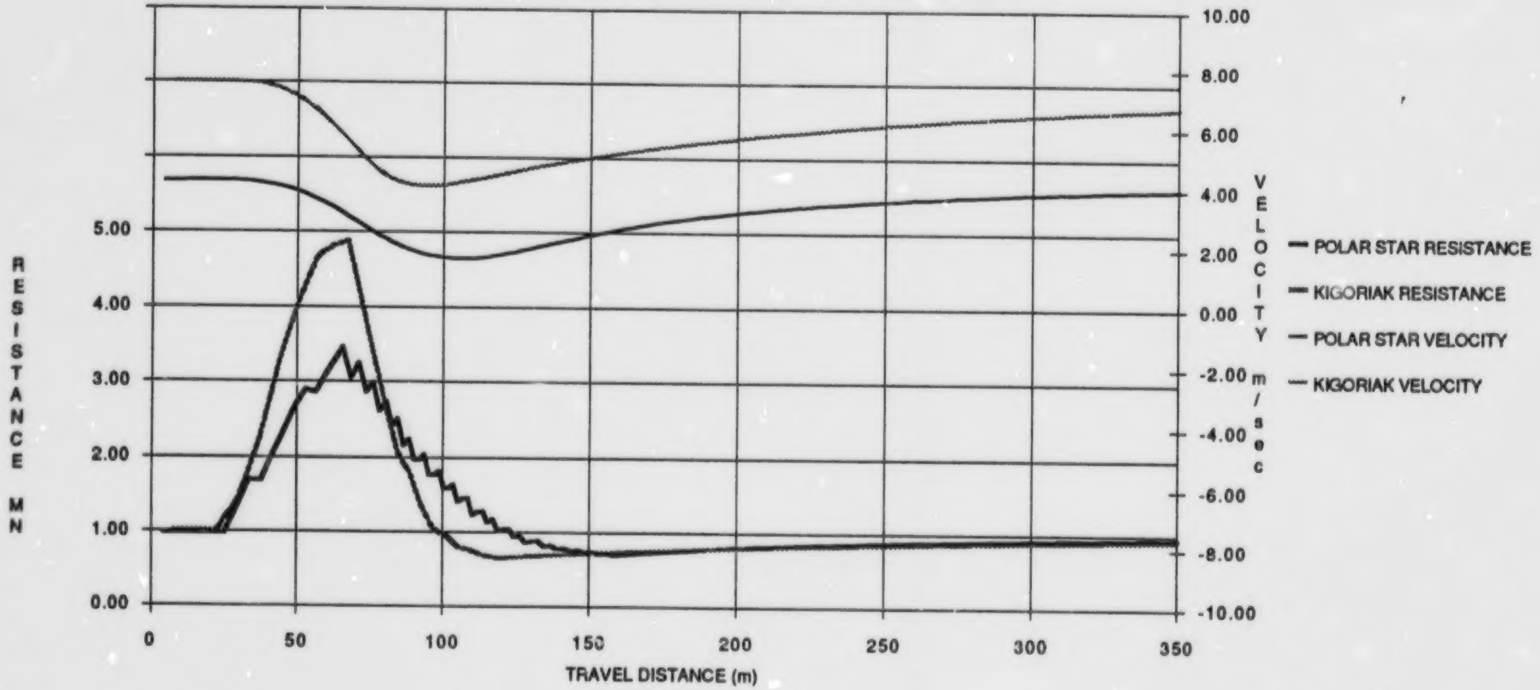
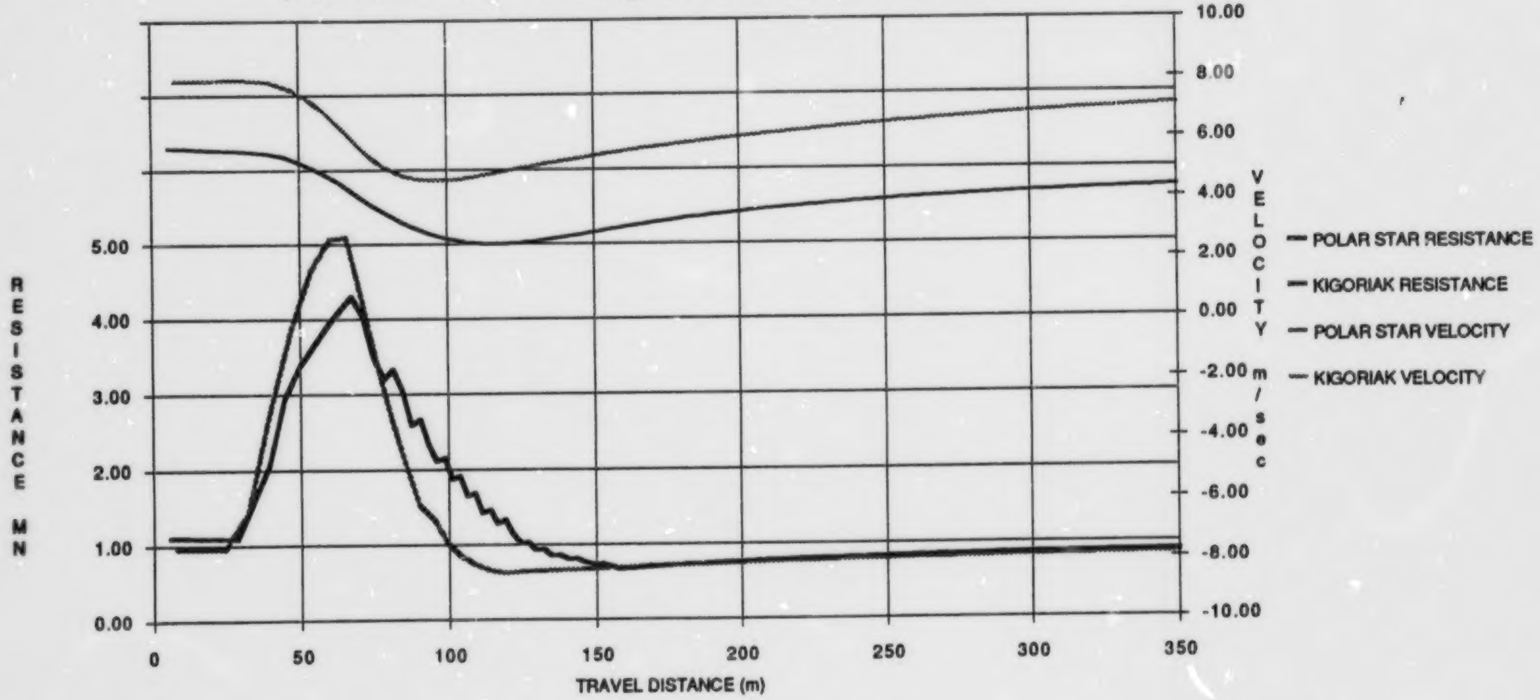


FIGURE 5.15

POLAR STAR & KIGORIAK COMPARISON(RIDGE 18)

(BOLLARD THRUST HELD EQUAL @1.8MN FOR BOTH SHIPS)



5.4.3 Comparison of POLAR STAR's And KIGORIAK's Performance In Ridges 17 And 18

Figures 5.14 and 5.15 compare the predicted performance of the KIGORIAK and the POLAR STAR for ridges 17 and 18, respectively. For these runs, each ship was assumed to have the same bollard thrust (of 1.8 MN).

The form of the predicted resistance versus distance and velocity versus distance curves for the KIGORIAK are similar to those for the POLAR STAR. However, the KIGORIAK's resistance during ridge penetration increases faster than does the POLAR STAR's for each of these ridges. This reflects the fact that the KIGORIAK is shorter than the POLAR STAR, particularly in the bow area where the resistance increases quickly as a function of penetration distance. The KIGORIAK also decelerates faster than the POLAR STAR, which is to be expected as the POLAR STAR has more inertia, being a more massive ship. The travel distance required for the ship to regain steady speed after transitting the ridge is important as this affects its capability to transit a sequence of ridges. At the end of the travel distance predicted for these runs (i.e., 350 m) both ships were still accelerating. For ridge 17, the POLAR STAR's velocity was almost equal to its "pre-ridge" velocity while the KIGORIAK's velocity was about 10% less than its steady speed in level ice. (See figure 5.14). For ridge 18, the velocity of both ships at the end of the model run was about 10% less than their steady speed (see figure 5.15).

Care should be exercised in using these results for comparisons between the KIGORIAK and the POLAR STAR hull forms. The KIGORIAK has less mass and beam, a shorter distance to maximum beam and shallower draft than the POLAR STAR. Furthermore, as the POLAR STAR was assumed to be operating in the diesel-electric mode for these runs, it had comparatively lower thrust (eg. on a thrust per unit-beam basis) than the KIGORIAK. If the POLAR STAR gas turbines were assumed to be operating, the travel distance predicted for it to accelerate back to steady-state travel after penetrating the ridge would have been greatly reduced. The results presented in this section provide an indication of the relative performance of the KIGORIAK and the POLAR STAR. However, more detailed analyses need to be carried out to allow general conclusions to be drawn.

5.4.4 Prediction of the Size of the "Average" Limiting Ridge

The model was run to predict the size of the "average" limiting ridge for the KIGORIAK and the POLAR STAR for a ridge width of 40 m. The thickness of the consolidated layer of the ridge was assumed to be one-third of that of the rubble ice. Runs were made for adjacent level ice thicknesses of 0.5 m, 1.0 m, and 1.25 m. The bollard thrust of the POLAR STAR was fixed at 1.85 MN (i.e. maximum thrust with diesel engines) while the bollard thrust of the KIGORIAK was set at 1.8 MN. The size of the "average" limiting ridge was determined iteratively by running the program for a range of ridge thicknesses.

Figures 5.16 to 5.18 show the predicted performance of the POLAR STAR in the limiting ridge for the three ice thicknesses and figures 5.19 to 5.21 show similar information for the KIGORIAK. Tables K.5 to K.10, in appendix K, provide a complete listing of these results. Table 5.6 summarizes the size of the "average" limiting ridge predicted for each case.

As would be expected, the program predicts that the size of the limiting ridge is highly dependent on the thickness of the adjacent level ice. Also, the program predicts that the KIGORIAK can transit a larger ridge, without being forced to ram, than can the POLAR STAR. This result is specific to the diesel-electric mode of operation for the POLAR STAR and reflects the fact that the KIGORIAK has lesser beam, draft and length than the POLAR STAR. Clearly, the POLAR STAR would be able to transit larger ridges without ramming if its gas turbines were in operation. Hence, the reader is cautioned against drawing general conclusions from these results.

Figure 5.16

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

POLAR STAR: LIMITING RIDGE (h=0.50m)

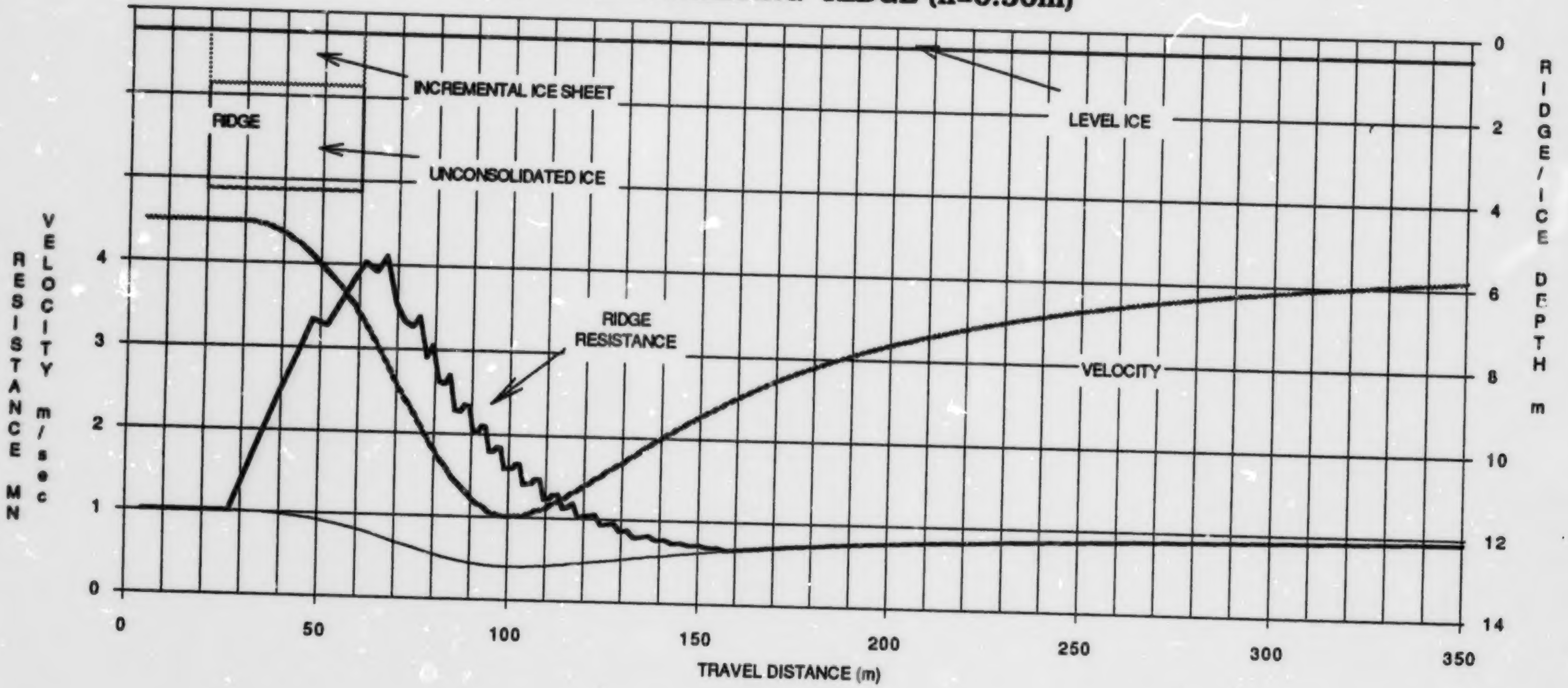


Figure 5.17

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

POLAR STAR: LIMITING RIDGE (h=1.00m)

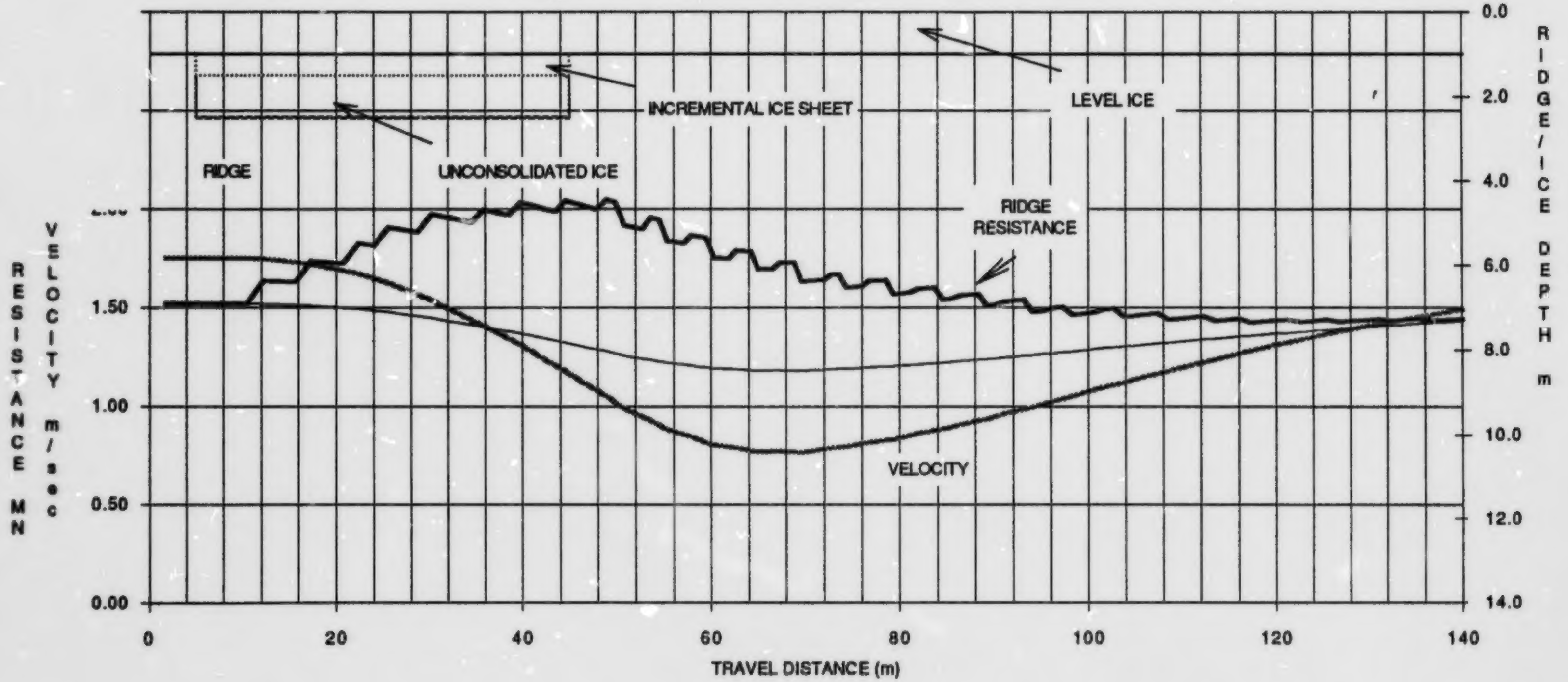


Figure 5.18

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

POLAR STAR: LIMITING RIDGE (h=1.25m)

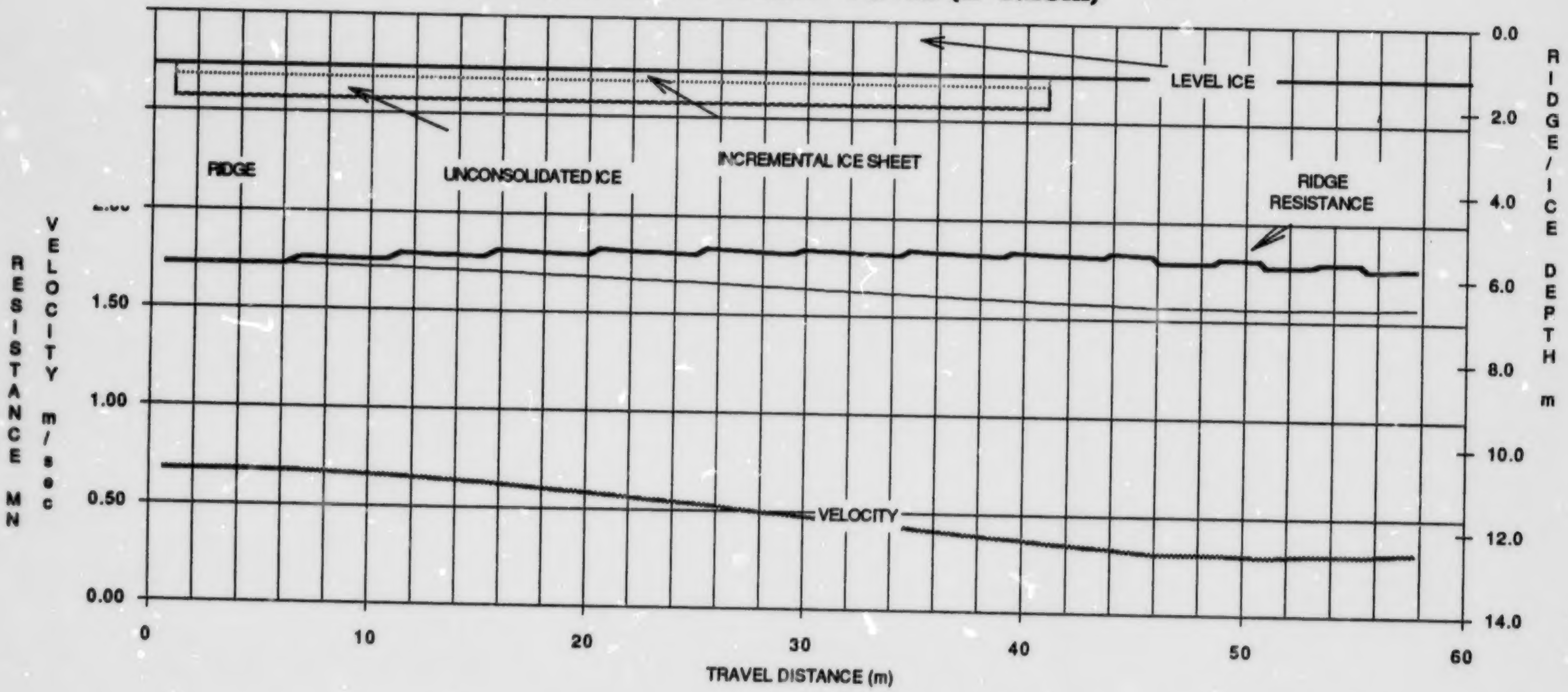


Figure 5.19

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

KIGORIAK: LIMITING RIDGE (h=0.50m)

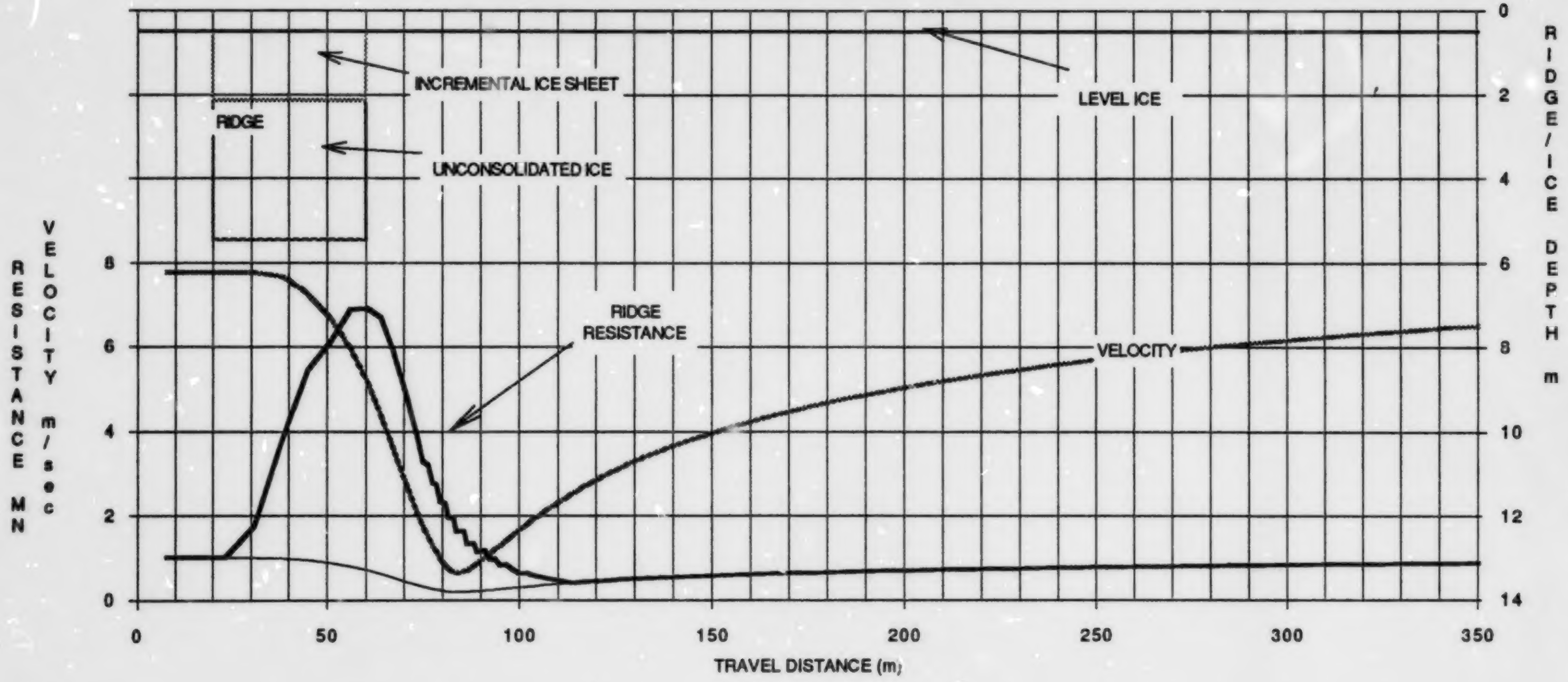


Figure 5.20

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

KIGORIAK: LIMITING RIDGE (h=1.00m)

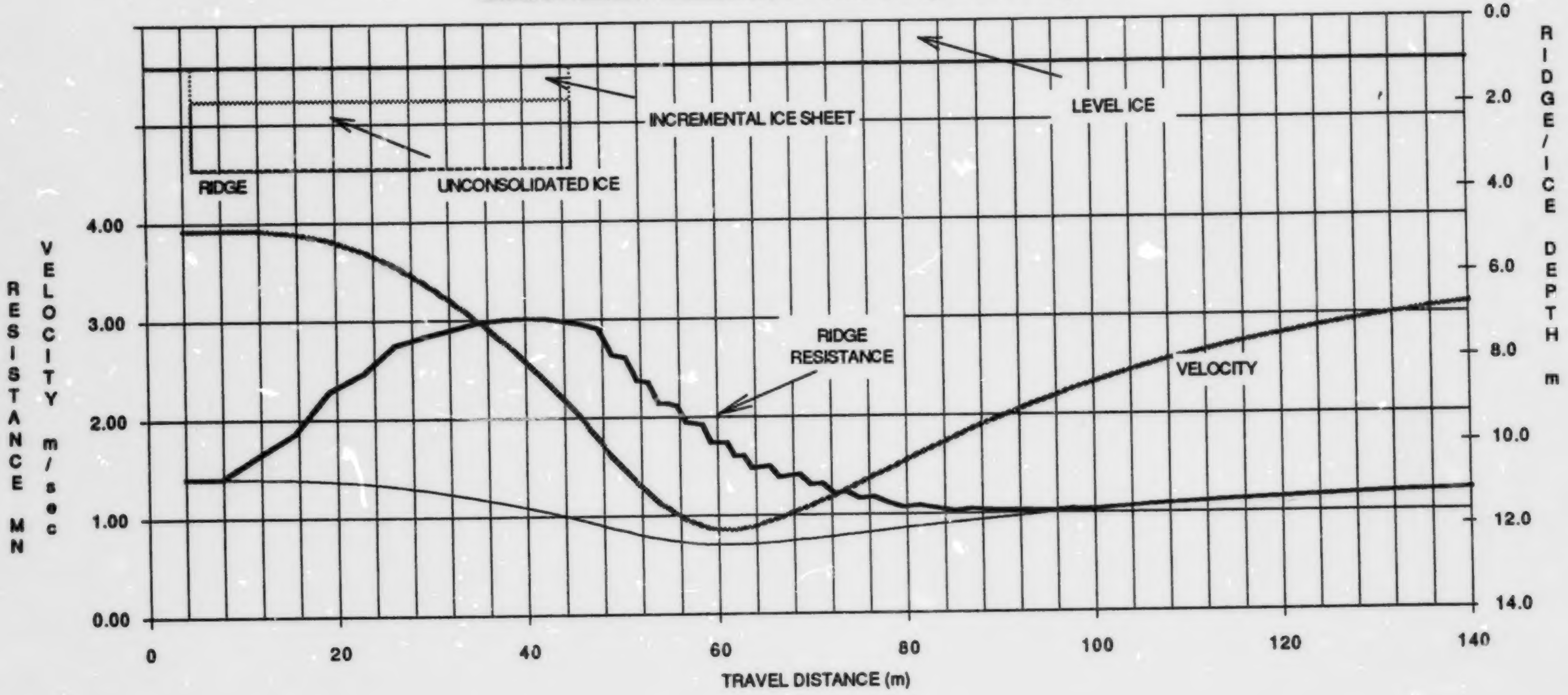


Figure 5.21

RESISTANCE & VELOCITY VS TRAVEL DISTANCE

KIGORIAK: LIMITING RIDGE (h=1.25m)

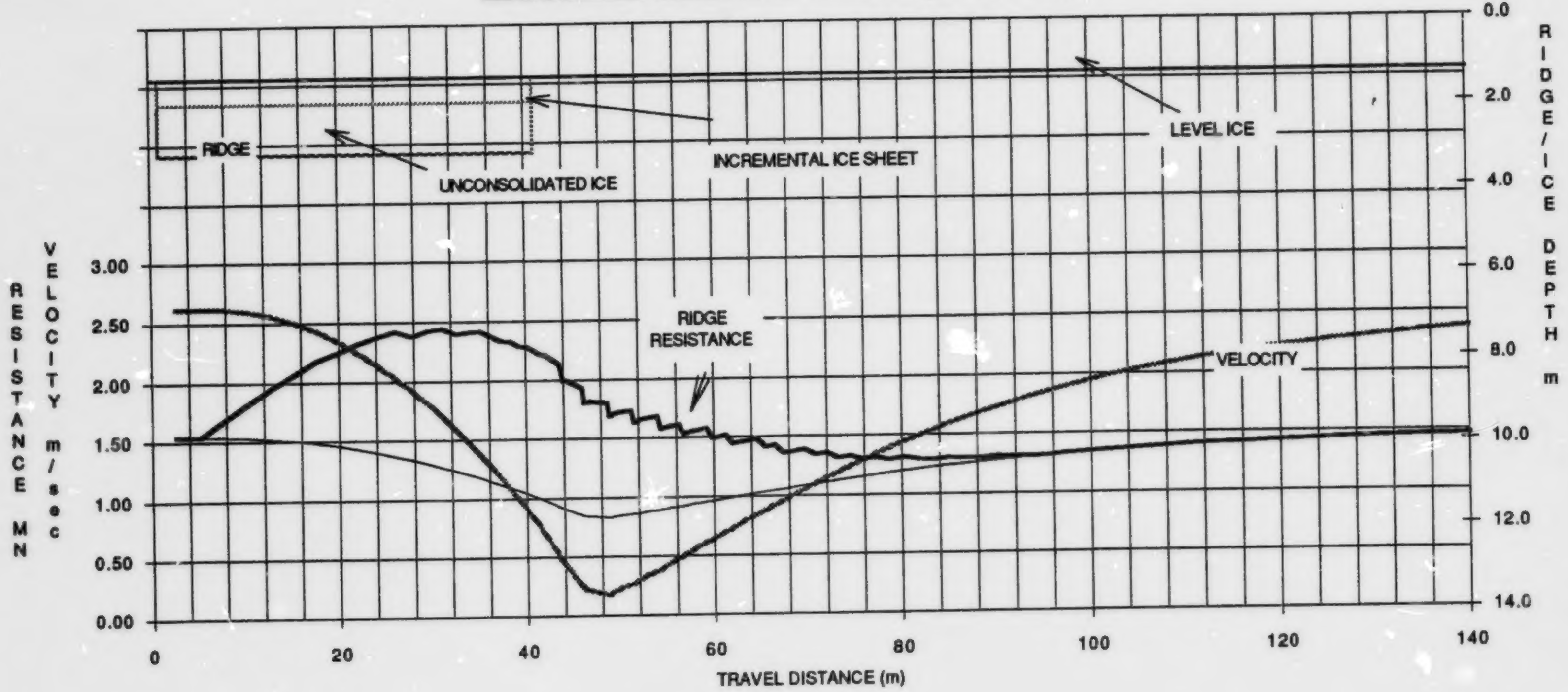


Table 5. 6

Predicted Size Of Limiting Ridge

Case #	Ship	Thickness of Adjacent Level Ice (m)	Ridge Width (m)	Entrance Velocity (m/sec)	Depth of Cons. Ice (m)	Depth of Uncons. Ice (m)
1	POLAR STAR	0.50	40	4.50	1.25	3.75
2	POLAR STAR	1.00	40	1.75	0.50	1.50
3	POLAR STAR	1.25	40	0.68	0.25	0.75
4	KIGORIAK	0.50	40	7.77	1.65	4.95
5	KIGORIAK	1.00	40	3.92	0.80	2.40
6	KIGORIAK	1.25	40	2.62	0.60	1.80

Note: The bollard thrust was set at 1.8 MN for both ships.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Basis for Conclusions

A series of model tests have been undertaken to evaluate a simplified ridge modelling approach. These tests were carried out at FTL's basin in Kanata using EGAD-doped refrigerated ice. Tests were conducted using a 19.1:1 scale model of the POLAR STAR and a 22.5:1 scale model of the KIGORIAK. Model tests were conducted for a range of thicknesses of rubble ice and sheet ice, and for a range of speeds. While the limitations of the testing facility resulted in data scatter, the results allow a preliminary evaluation of the concept.

A simplified numerical model has been developed to predict ship performance during single-pass ramming. Some of the model's simplifications and limitations include:

- an implicit treatment of open water resistance.
- the treatment of added mass as a constant proportion of the ship's displacement.
- an assumption that there is no thrust deduction due to ice.
- the utilization of a semi-empirical relationship to predict the ship's level ice resistance.
- a limitation of applicability to cases where the ship has forward speed.
- a limitation of applicability to "average" ridges as opposed to field ridge profiles.

Key inputs include the level ice resistance, the broken ice resistance, ship resistance vs distance during entry into an ice edge, and ship thrust vs velocity in open water. Available model test data were used to define most input parameters.

The numerical model was exercised to predict the full scale performance of the POLAR STAR and KIGORIAK in two actual field ridges. It was also used to predict the size of the average limiting ridge for a range of adjacent level ice thicknesses for the POLAR STAR and the KIGORIAK.

6.2 Conclusions

The results of the study allow some preliminary conclusions, as follows:

Physical Model Tests:

(a) The physical testing approach evaluated in this program provides a simple ridge modelling method.

(b) Based on limited calibration with two first year ridges, the simplified ridge modelling approach predicts incremental penetration energies for the POLAR STAR that are of the same order as the field data. The predicted incremental penetration energies were about 30% to 40% less than the field data. However, when the model scale broken ice resistances were corrected for density differences between model scale and full scale ice, the results were within 5% of the field data.

(c) The form of the incremental resistance vs distance curves predicted by the model tests is generally similar to the form of those measured in the field.

(d) The model test data obtained for the penetration phase are scattered, up to a maximum of about ± 50% of the mean for the broken ice and level ice tests. This reflects limitations of the facility as well as icebreaking processes. It is, therefore, concluded that several penetration tests are required with this approach to establish a representative average.

(e) The dependence of resistance, particularly broken ice resistance, on discrepancies in buoyancy forces due to density differences between model scale and full scale ice has the potential to greatly affect the conclusions of this study. Data are not available to evaluate this effect, which requires further study.

Numerical Model:

(f) The numerical model developed in this project provides an effective tool for first-order prediction of ship performance during single-pass ramming. Based on a limited calibration with full scale data, it is capable of reproducing the measured performance of the POLAR STAR in two field ridges.

(g) The model predicts trends regarding the relative performance of the KIGORIAK and the POLAR STAR that are credible. However, direct comparisons cannot be made as there are significant differences in mass, beam, length and draft between these ships.

(h) The model predicts trends regarding the size of the limiting ridge that are credible. The size of the limiting ridge is reduced greatly as the thickness of the adjacent level ice is increased. It predicts that the KIGORIAK can transit a larger ridge without ramming than can the POLAR STAR if the thrust is equal for these two ships. This result reflects the fact that the KIGORIAK has less beam and draft than the POLAR STAR.

6.3 Recommendations

The following additional work is recommended:

(a) Collection of additional single-pass ridge penetration data. Additional field tests should be conducted with hull forms that are significantly different than the POLAR STAR's and in larger ridges which are closer to the size of the "limiting" ridge. Subsequent model scale-full scale comparisons should then be carried out.

(b) This test program should be continued in a larger facility, to provide a more accurate database for rubble ice resistance and for the penetration resistance of level ice and rubble ice.

(c) Parametric investigation of resistance, particularly in rubble ice, on the ice density using model tests. The results of these tests should be compared with available full scale data for the resistance of unconsolidated ridges, such as [4].

(d) Development of the numerical model should be continued. Sensitivity analyses should first be conducted. Improvements should then be made, as appropriate, to the model's basic algorithms, (e.g., prediction of level ice resistance, rubble resistance, thrust vs. speed, added mass). Finally, its user-friendliness should be improved.

(e) The numerical model should be extended to include ramming.

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EVALUATION OF A
SIMPLIFIED RIDGE MODELLING METHOD

VOLUME II - APPENDICES

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Policy and Coordination Group
Transport Canada

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16. Abstract

A project has been undertaken to evaluate, and develop a database for, a simplified method for modelling ridges in the ice model basin. This method is aimed at simulating the incremental penetration energy, which is defined as the additional energy required by the ship to penetrate the ridge over that amount which would have been expended had there not been a ridge in the ice. Efforts were made to model this incremental penetration energy by conducting tests with separate sheets of level ice and rubble ice, only. The penetration phase of these tests (in which the model entered the ice edge) was analyzed to predict the resistance and energy for a ridge of limited width.

Tests were conducted at FTL's laboratory in Kanata using refrigerated, EGAD-doped, model ice. Tests were conducted with a 19.1:1 scale model of the USCGC POLAR STAR and a 22.5:1 scale model of the MV KIGORIAK.

A simple computer program was written to predict icebreaker resistance and performance in ridges up to the vessel's limiting ridge capability. The peak resistance of the POLAR STAR compares within 5% of the field ramming data for this ship after corrections are applied to the model test and field data. The computer program was run for a number of cases to predict the size of the limiting ridge for the POLAR STAR and the MV KIGORIAK.

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16. Résumé

La recherche dont il est rendu compte concerne l'évaluation d'une méthode simplifiée de modélisation des crêtes de pression, et la mise en place de la base de données correspondante. Le modèle ainsi obtenu permet de calculer le surplus d'énergie (incrément) que doit développer un brise-glace chargeant une crête de pression, par rapport à l'énergie dépensée si cette crête n'existait pas. Des essais sur maquettes ont été menés dans des glaces uniformes et des glaces fragmentées, afin de parvenir à des prévisions sur la valeur d'énergie de l'incrément requis. L'analyse de la portion de ces essais durant laquelle la proue de la maquette pénètre dans la glace a permis de dégager des prévisions sur les valeurs de résistance et d'énergie à l'égard d'une crête de largeur finie.

Les essais menés dans le bassin des glaces de Fleet Technology Ltd. à Kanata ont mis en oeuvre une glace modèle réfrigérée et dopée, une maquette 1:19,1 du brise-glace POLAR STAR et une maquette 1:22,5 du KIGORIAK.

Un programme informatique simple a été rédigé, permettant de prévoir les valeurs de résistance à l'avancement et les distances de franchissement de différentes crêtes, y compris celles que le navire est incapable de franchir. Les prévisions ainsi obtenues sur l'aptitude du POLAR STAR se comparent aux données réelles le concernant, dans une marge de 5 p. 100. Ce programme a servi à définir les limites de l'aptitude du POLAR STAR et du KIGORIAK à franchir des crêtes dans des conditions variées.

17. Mots clés
Brise-glace,
modélisation des glaces,
crêtes de pression.

18. Diffusion
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SUMMARY OF TEST MATRIX AND STEADY STATE RESISTANCES FOR TESTS CARRIED OUT WITH THE MV KIGORIAK

Sheet #	Test #	Ice Type	Ship Speed (m/s)	Avg Ice Thick (mm)	Ship Trim (deg)	Steady-State Resistance (N) (See Note 2)
1	1-1	Sheet	0.4	25	0	30
1	1-2	Sheet	0.8	25	0	60
1	1-3	Rubble	0.4	70	0	40
1	1-4	Rubble	0.8	70	0	40
1	1-5	Rubble	0.4	160	0	100
1	1-6	Rubble	0.8	149	0	90
2	2-2	Level	0.4	60	0	150
2	2-3	Level	0.8	59	0	210
2	2-4	Level	0.4	59	2.4 by stern	220
2	2-5	Level	0.8	59	2.4 by stern	190
2	2-6	Rubble	0.4	65	2.4 by stern	50
2	2-7	Rubble	0.8	65	2.4 by stern	60
2	2-8	Rubble	0.4	123	2.4 by stern	70
2	2-9	Rubble	0.8	118	2.4 by stern	80
2	2-10	Rubble	0.4	133	0	60
2	2-11	Rubble	0.8	132	0	90
2	2-12	Rubble	0.4	68	0	60
2	2-13	Rubble	0.8	83	0	70
3	3-1	Sheet	0.4	92	0	600
3	3-2	Sheet	0.8	89	0	700
3	3-3	Sheet	0.4	98	2.4 by stern	1100
3	3-4	Sheet	0.8	98	2.4 by stern	1900
3	3-5	Rubble	0.4	197	2.4 by stern	180
3	3-6	Rubble	0.8	197	2.4 by stern	200
3	3-7	Rubble	0.4	190	0	190
3	3-8	Rubble	0.8	198	0	210
3	3-9	Rubble	0.4	308	0	210
3	3-10	Rubble	0.8	260	0	300
3	3-11	Rubble	0.4	353	2.4 by stern	220
3	3-12	Rubble	0.8	323	2.4 by stern	210

NOTE: (1) All values are model scale.

(2) As the run length was very short, the measured steady-state resistances are first-order only. See section 3.3.

SUMMARY OF TEST MATRIX AND STEADY STATE RESISTANCES FOR TESTS CARRIED OUT WITH THE USCGC POLAR STAR

Sheet #	Test #	Ice Type	Ship Speed (m/s)	Avg. Ice Thick. (mm)	Steady-State Resistance (N) (See Note 3)
4	4-1	Sheet	0.4	27	90
4	4-3	Rubble	0.4	122	80
5	5-1	Sheet	0.4	66	120
5	5-3	Rubble	0.4	210	100
6	6-1	Sheet	0.4	62	150
6	6-3	Rubble	0.4	122	110
6	6-5	Rubble	0.4	245	170
7	7-1	Sheet	0.4	94	320
7	7-3	Rubble	0.4	168	110
7	7-5	Rubble	0.4	343	230
DS1	DS1-7	Rubble	0.1	280	180
DS1	DS1-8	Rubble	0.2	277	190
DS1	DS1-9	Rubble	0.4	257	220
DS2	DS2-1	Sheet	0.1	50	n/a-See Note 2
DS2	DS2-2	Sheet	0.4	52	170
DS2	DS2-3	Rubble	0.4	129	100
DS2	DS2-4	Rubble	0.2	119	80
DS2	DS2-5	Rubble	0.1	106	60
DS2	DS2-6	Rubble	0.4	247	360
DS2	DS2-7	Rubble	0.2	243	350
DS2	DS2-8	Rubble	0.1	241	300
DS3	DS3-1	Sheet	0.1	92	n/a-See Note 2
DS3	DS3-2	Sheet	0.4	95	320
DS3	DS3-3	Rubble	0.1	160	100
DS3	DS3-4	Rubble	0.2	174	150
DS3	DS3-5	Rubble	0.4	170	140
DS3	DS3-6	Rubble	0.1	307	270
DS3	DS3-7	Rubble	0.2	352	350
DS3	DS3-8	Rubble	0.4	337	460

NOTES:

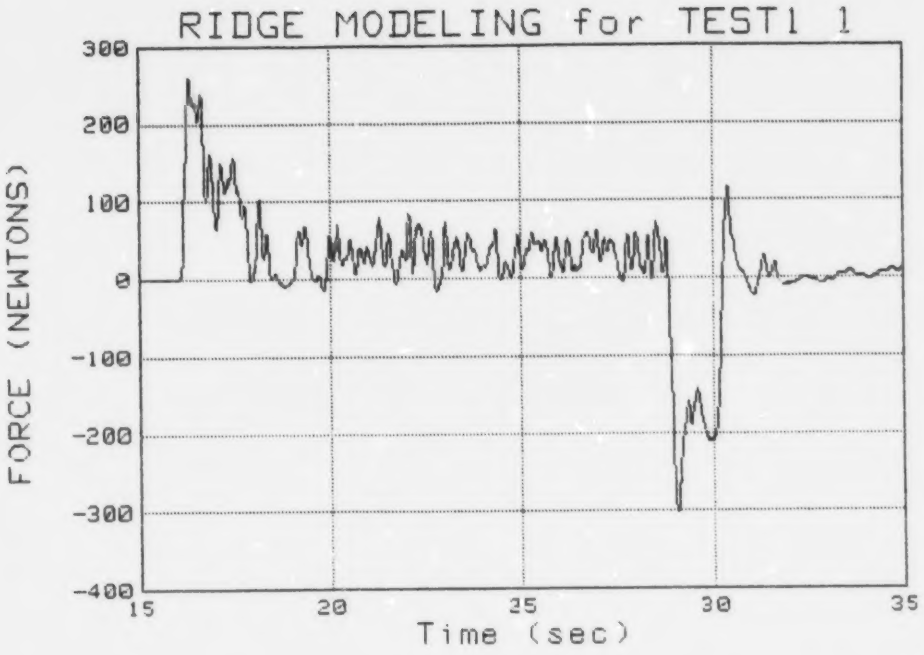
(1) All values are model scale.

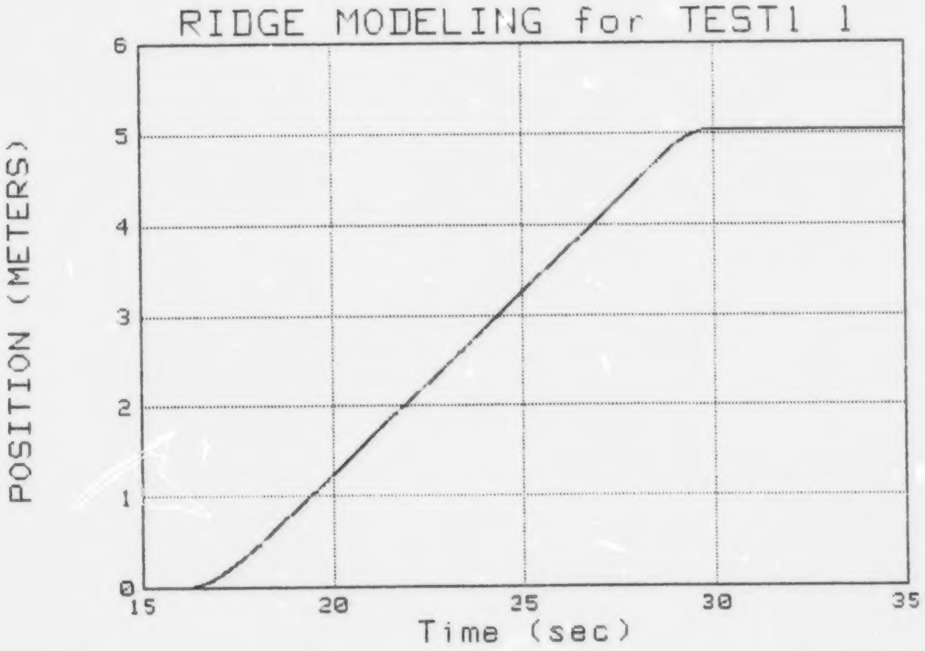
(2) The model was only partially embedded (to about the point of maximum beam) during this test.

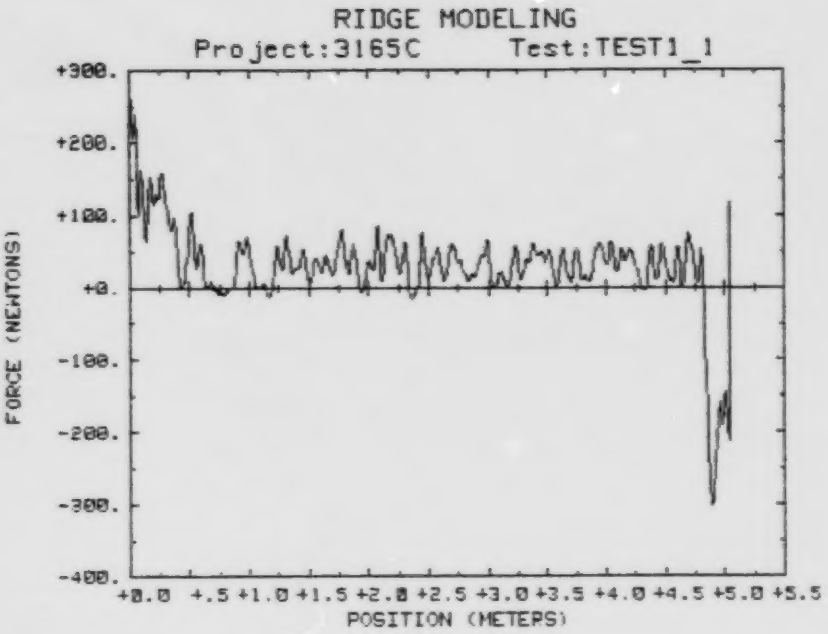
(3) As the run length was very short, the measured steady-state resistances are first-order only. See section 3.3.

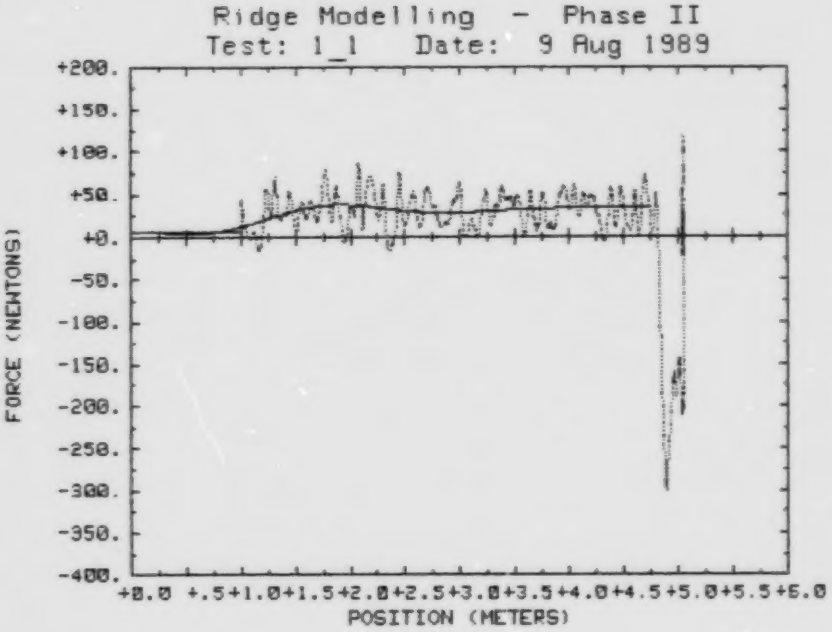
APPENDIX A

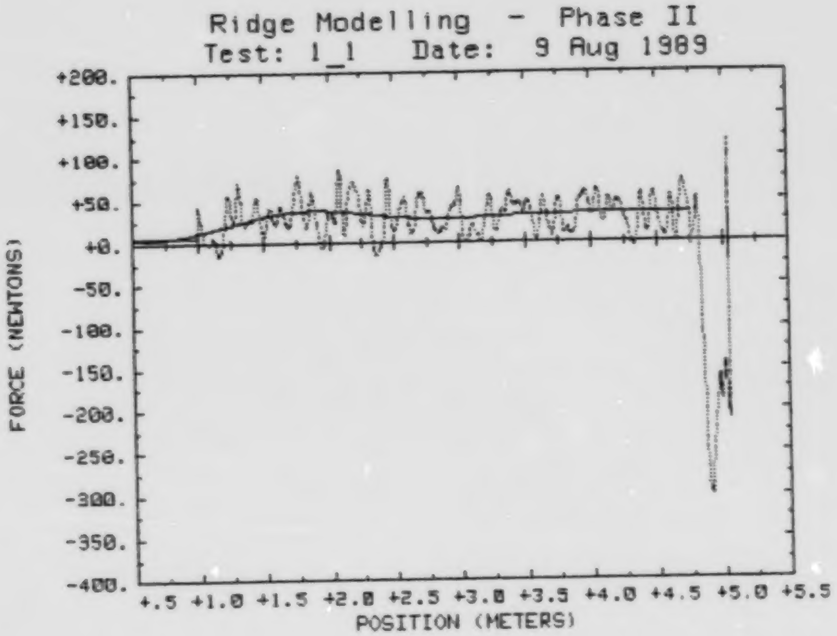
TEST DATA FOR SHEET #1

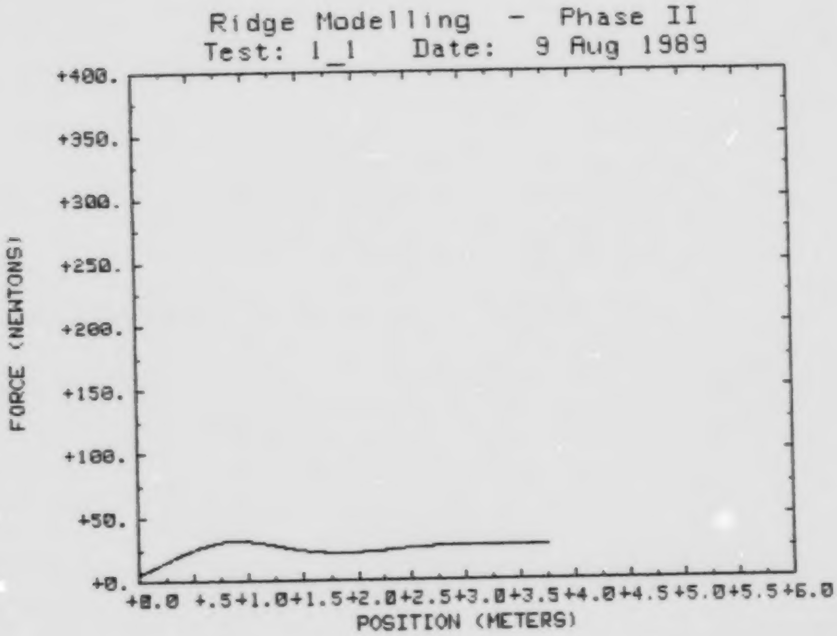

RIDGE MODELING for TEST1 1
FORCE (NEWTONS)
300
200
100
0
-100
-200
-300
-400
15
20
25
30
35
Time (sec)

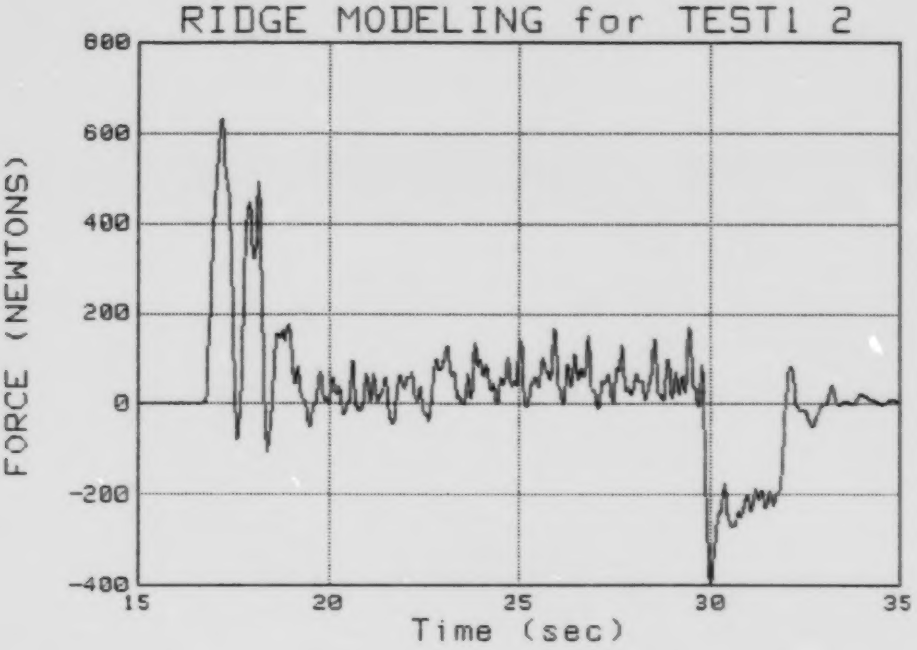

RIDGE MODELING for TEST1 1
POSITION (METERS)
6
5
4
3
2
1
0
15
20
25
30
35
Time (sec)

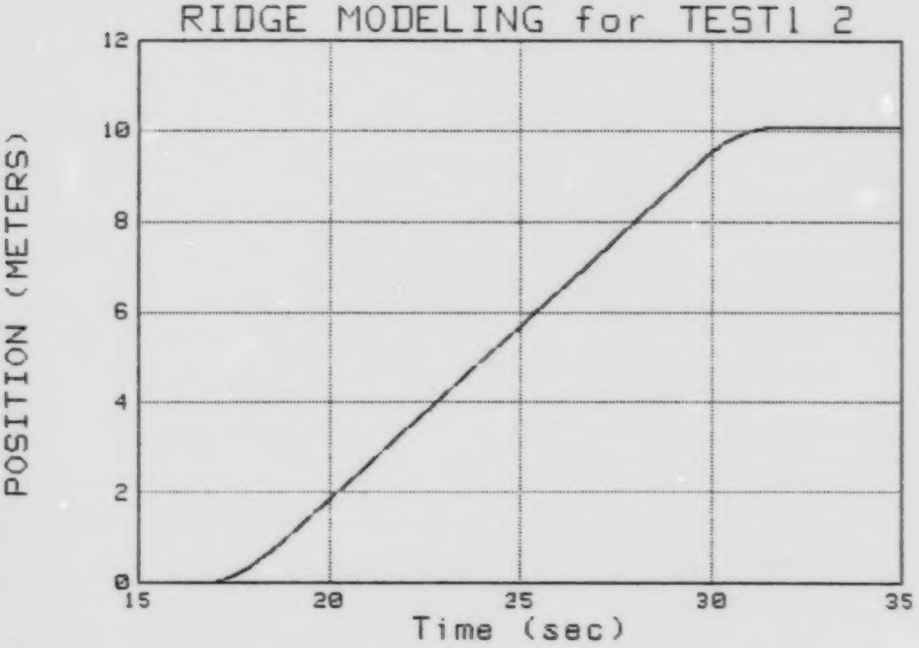

RIDGE MODELING
Project:3165C Test:TEST1_1
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
+0.0 +.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5
POSITION (METERS)


Ridge Modelling - Phase II
Test: 1_1 Date: 9 Aug 1989
FORCE (NEWTONS)
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
-300.
-350.
-400.
+0.0 +.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0
POSITION (METERS)

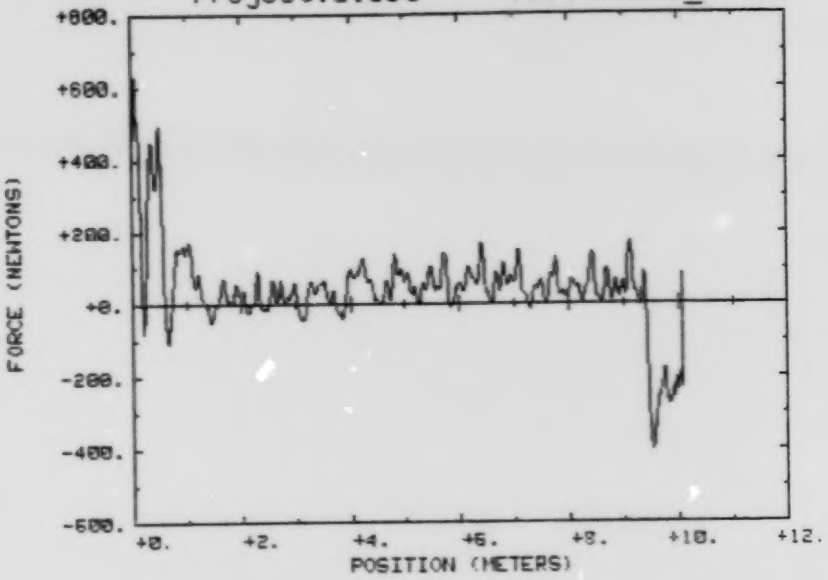

Ridge Modelling - Phase II
Test: 1_1 Date: 9 Aug 1989
FORCE (NEWTONS)
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
-300.
-350.
-400.
+.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5
POSITION (METERS)


Ridge Modelling - Phase II
Test: 1_1 Date: 9 Aug 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0 +.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0
POSITION (METERS)

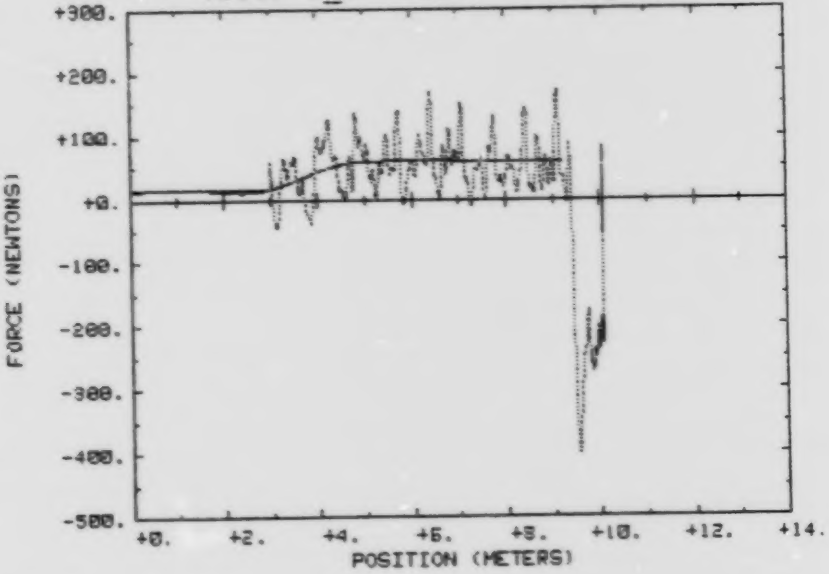

RIDGE MODELING for TEST1 2
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
15
20
25
30
35
Time (sec)

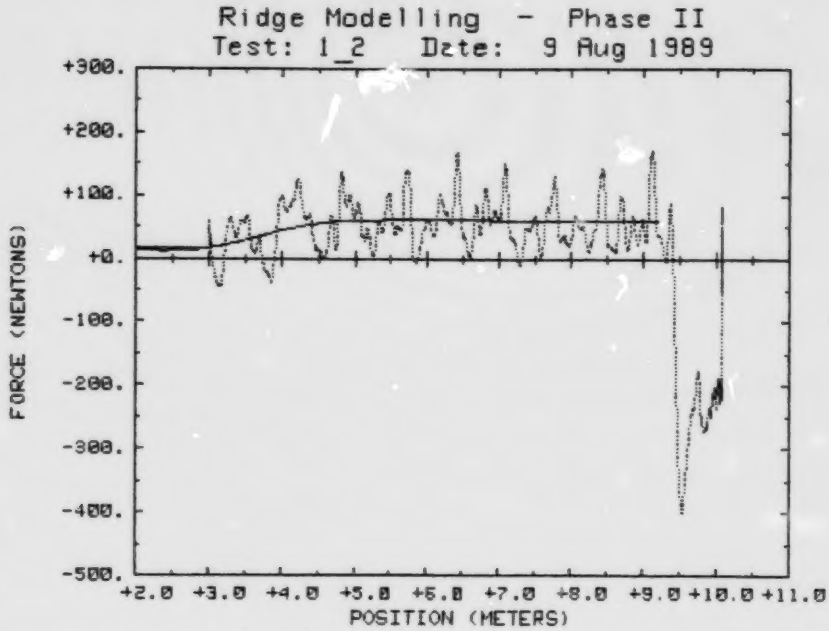

RIDGE MODELING for TEST1 2
POSITION (METERS)
12
10
8
6
4
2
0
15
20
25
30
35
Time (sec)

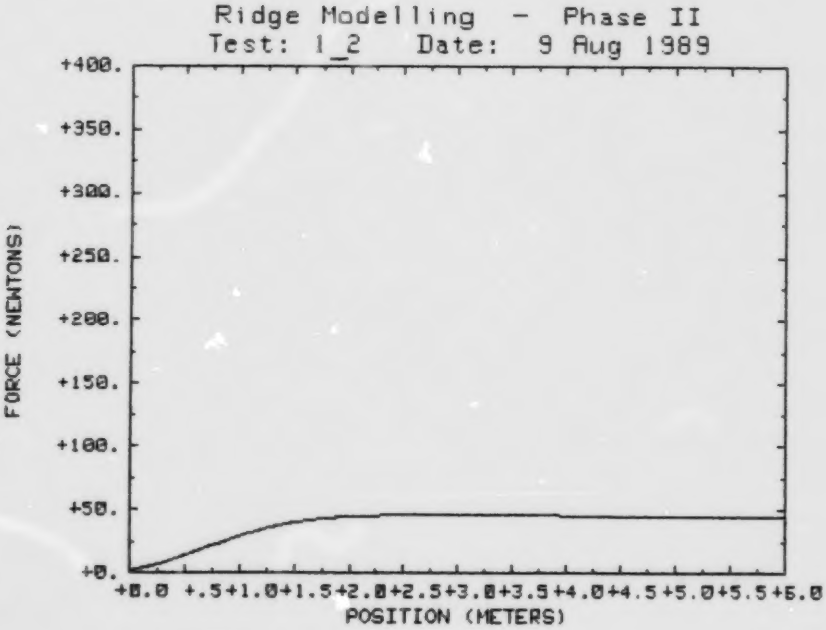
RIDGE MODELING
Project:3165C Test:TEST1_2

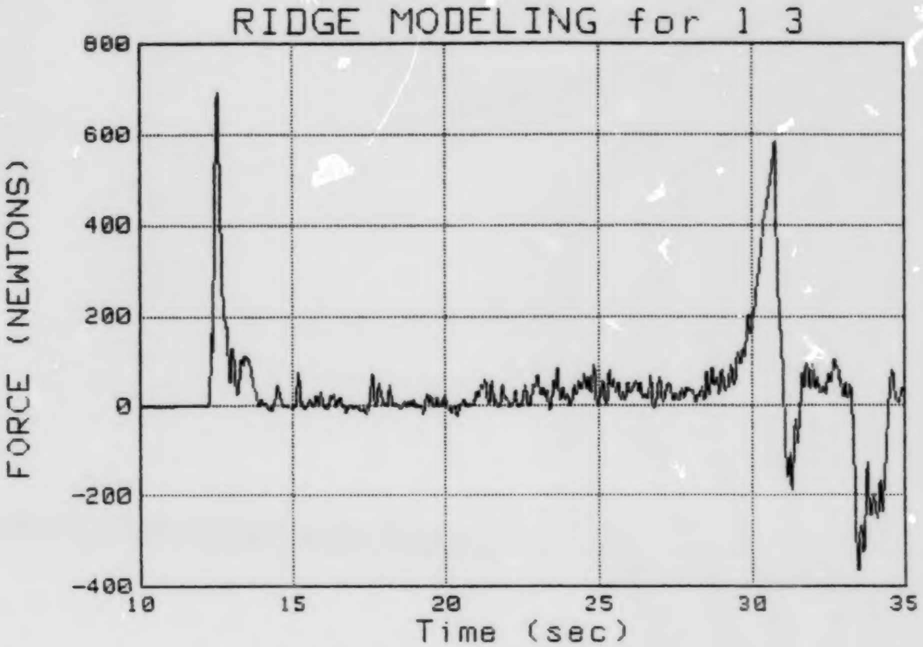


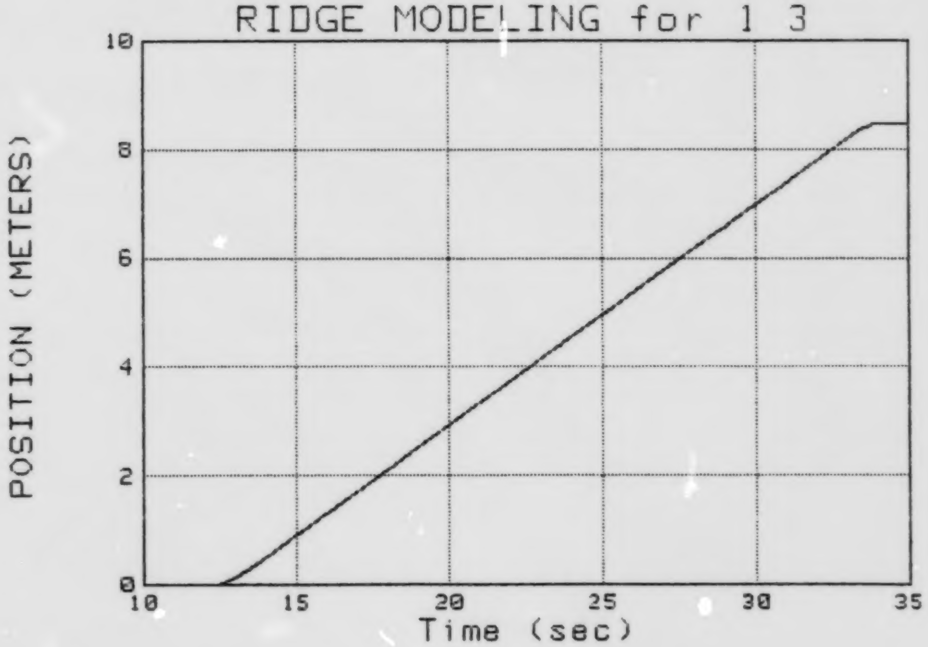
Ridge Modelling - Phase II
Test: 1_2 Date: 9 Aug 1989

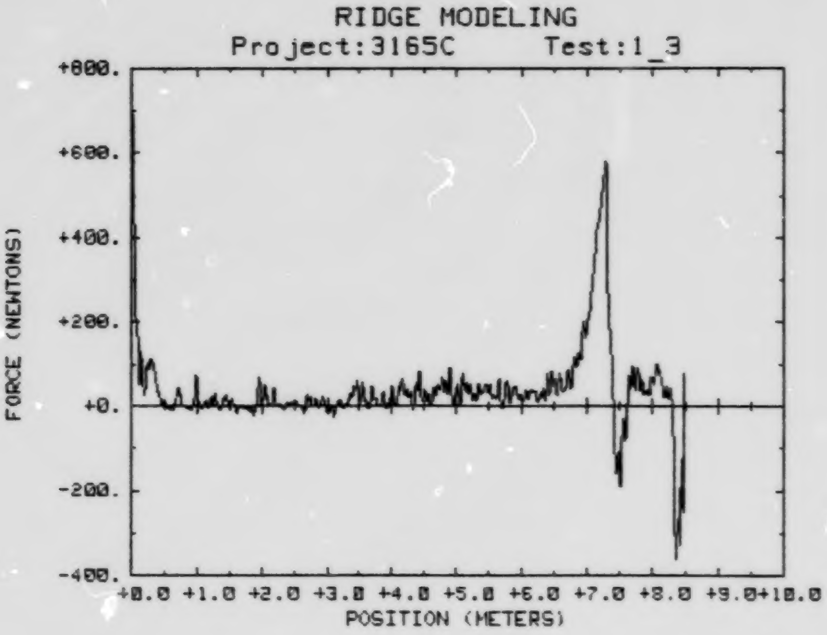


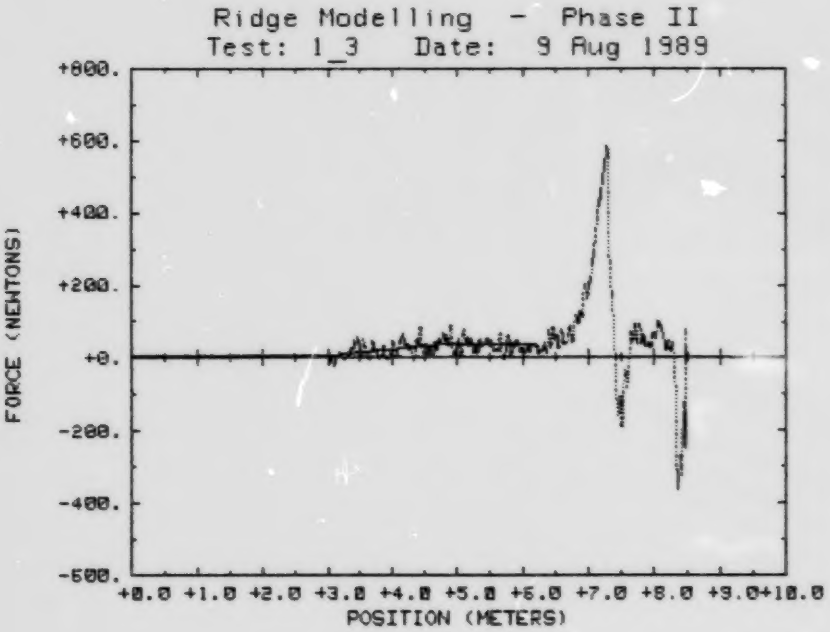

Ridge Modelling - Phase II
Test: 1_2 Date: 9 Aug 1989

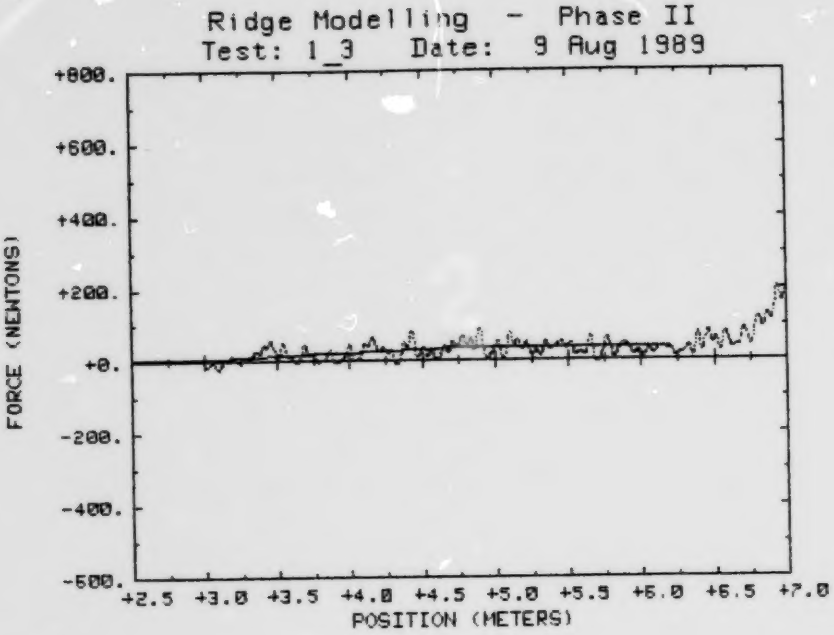

Ridge Modelling - Phase II
Test: 1_2 Date: 9 Aug 1989

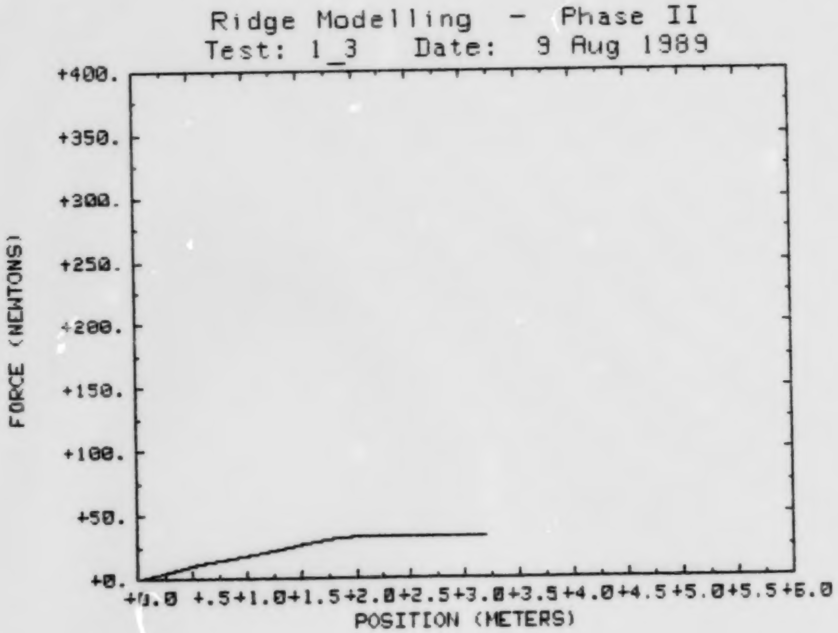

RIDGE MODELING for 1 3
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
10
15
20
25
30
35
Time (sec)

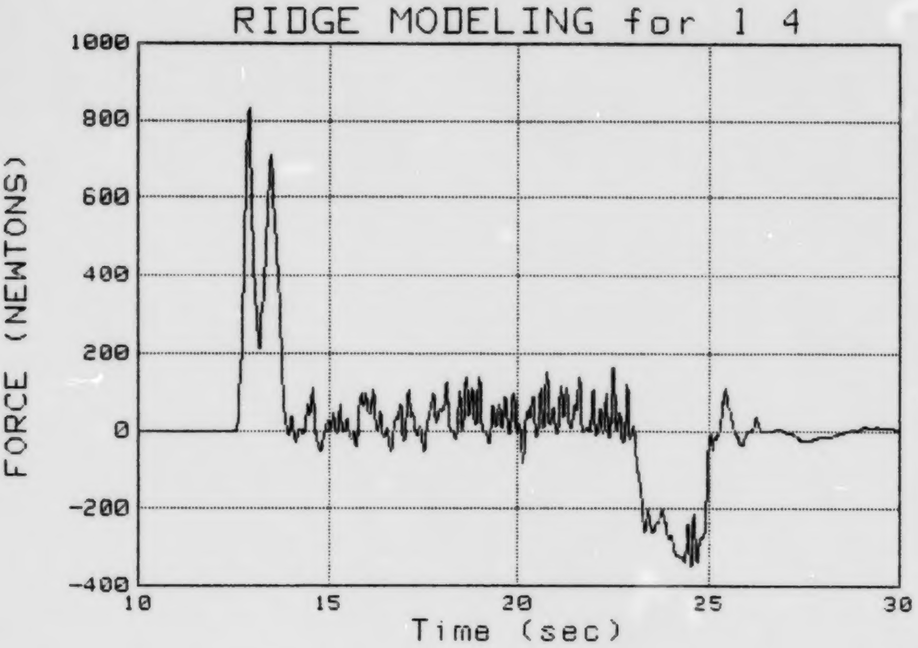

RIDGE MODELING for 1 3
POSITION (METERS)
10
8
6
4
2
0
10
15
20
25
30
35
Time (sec)


RIDGE MODELING
Project:3165C Test:1_3
+800.
+600.
+400.
+200.
+0.
-200.
-400.
FORCE (NEWTONS)
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

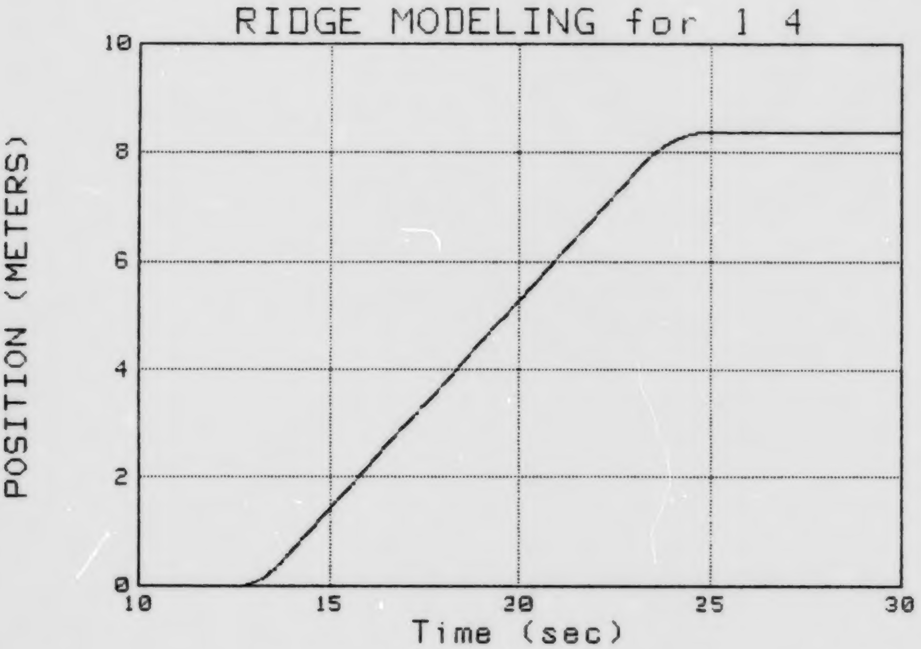

Ridge Modelling - Phase II
Test: 1_3 Date: 9 Aug 1989
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
FORCE (NEWTONS)
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 1_3 Date: 9 Aug 1989
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
FORCE (NEWTONS)
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
+6.5
+7.0
POSITION (METERS)

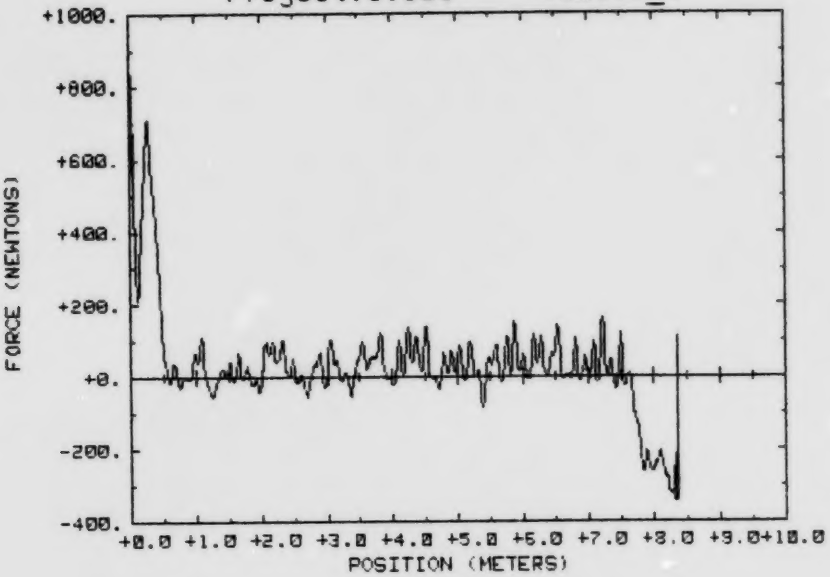

Ridge Modelling - Phase II
Test: 1_3 Date: 9 Aug 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)



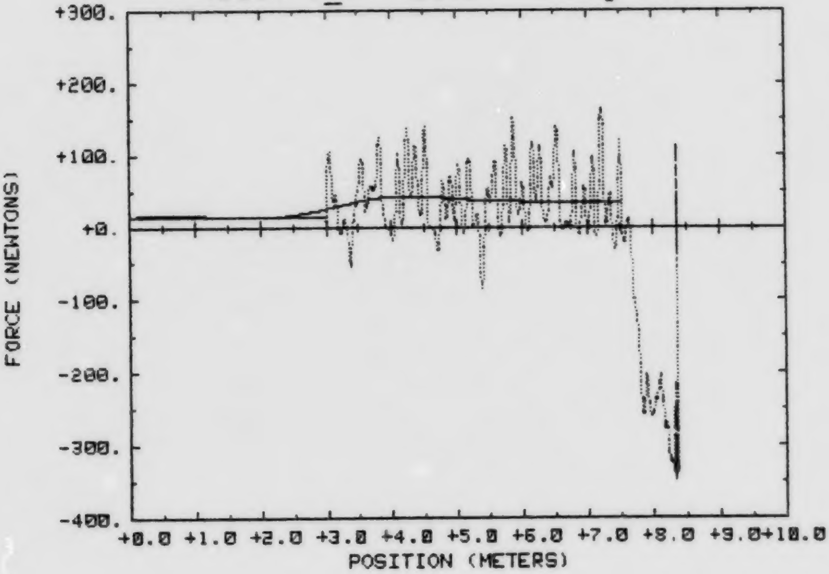
RIDGE MODELING for 1 4



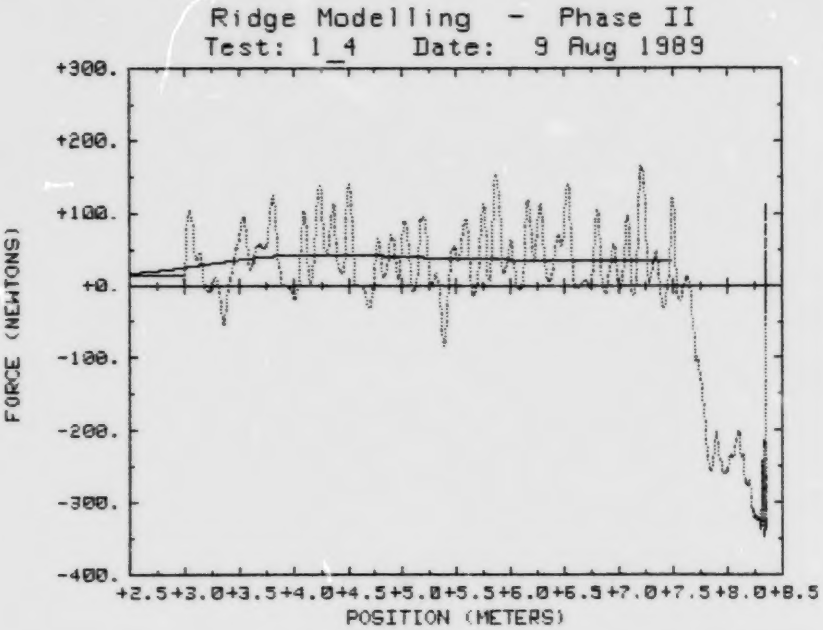
RIDGE MODELING for 1 4

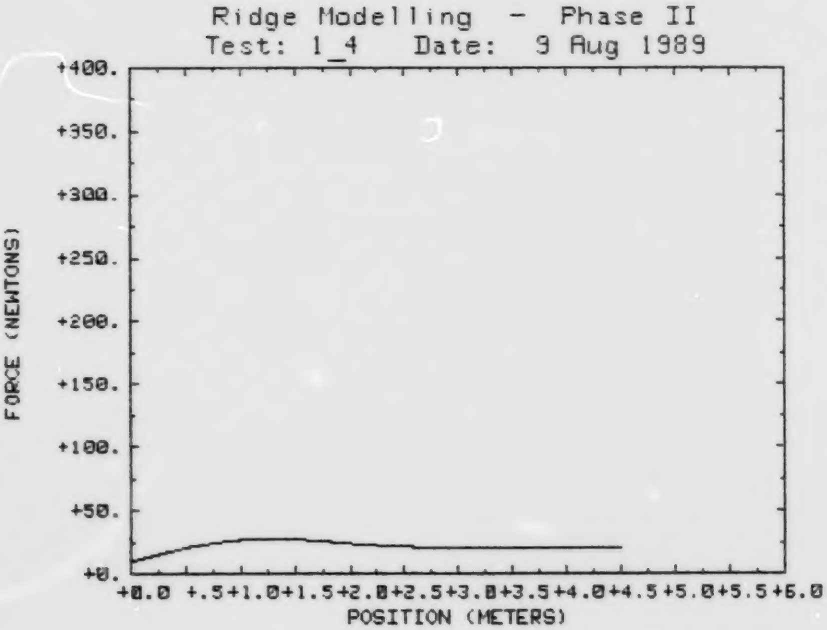


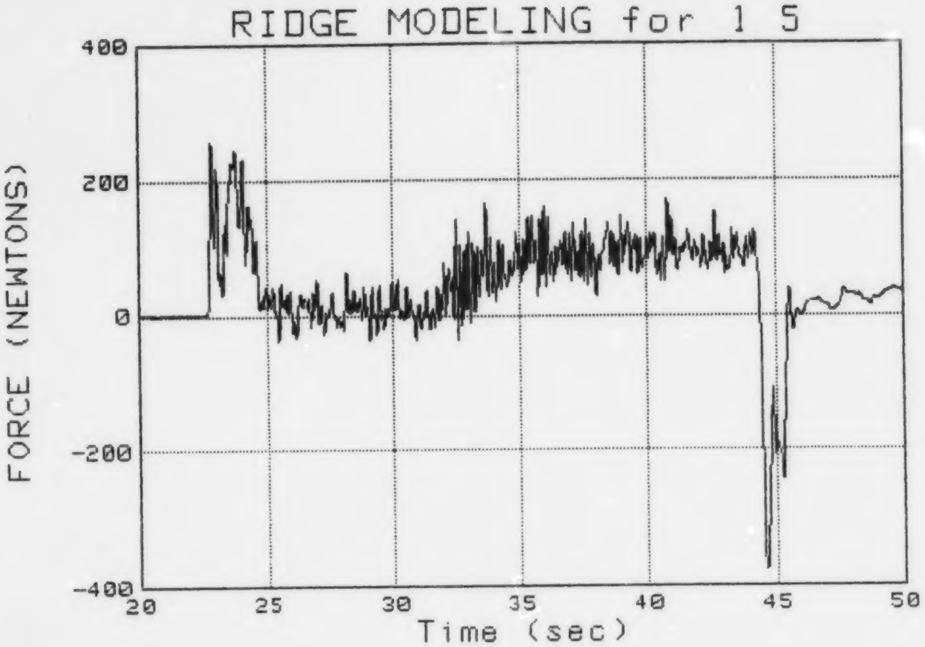
RIDGE MODELING
Project:3165C Test:1_4

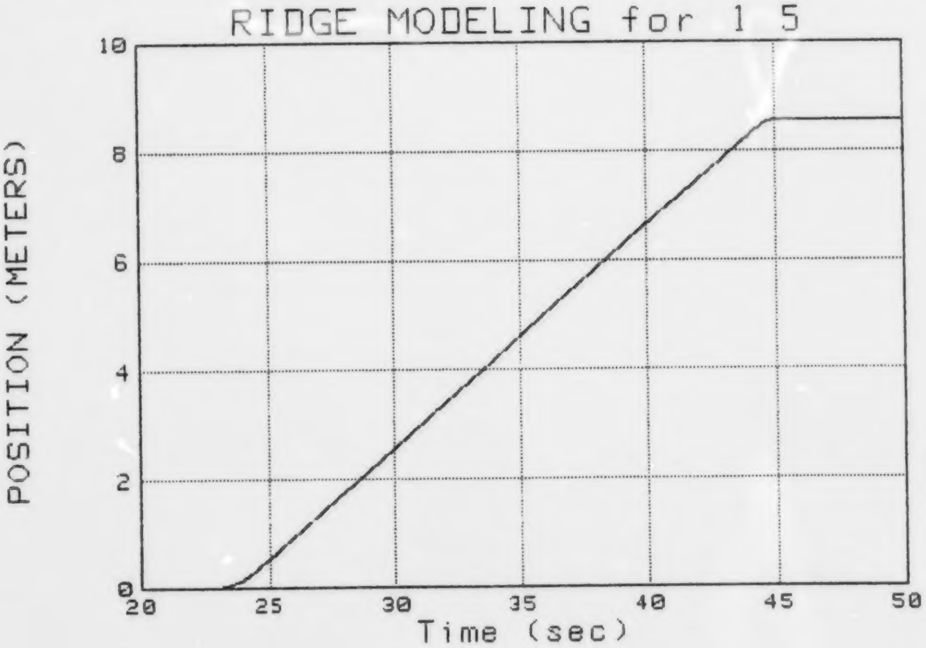


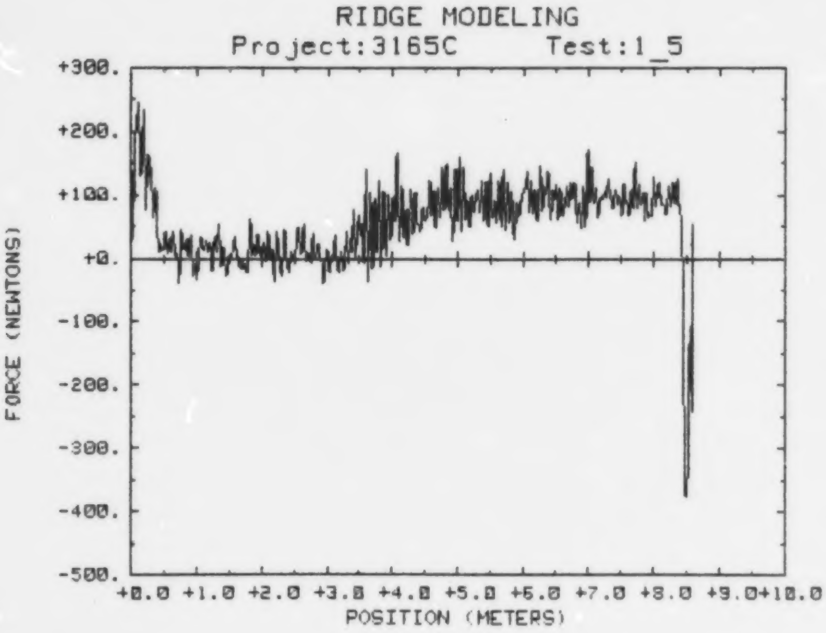
Ridge Modelling - Phase II
Test: 1_4 Date: 9 Aug 1989

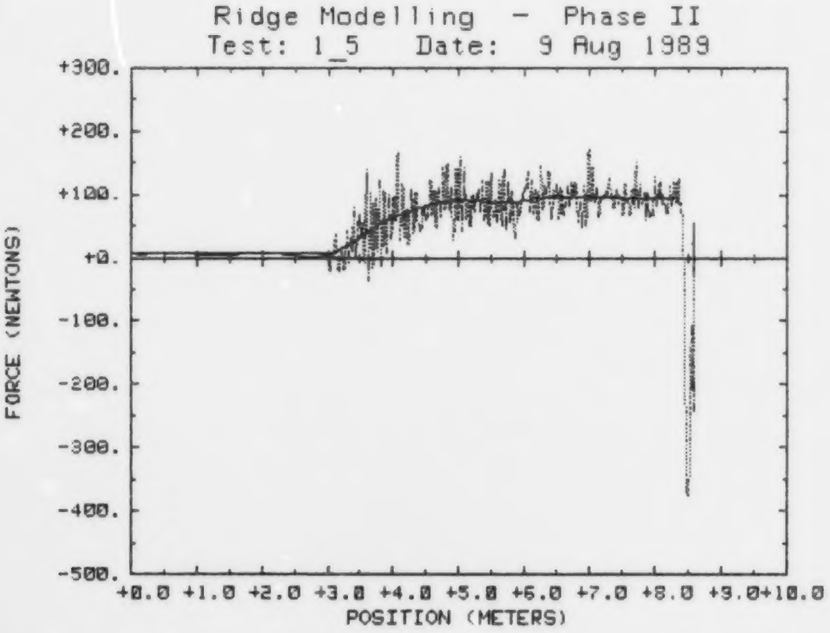

Ridge Modelling - Phase II
Test: 1_4 Date: 9 Aug 1989


Ridge Modelling - Phase II
Test: 1_4 Date: 9 Aug 1989

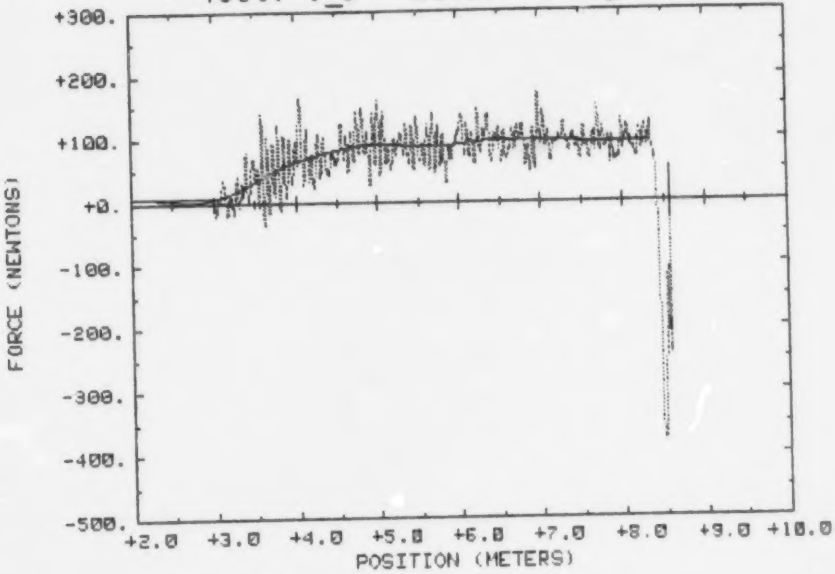

RIDGE MODELING for 1 5
FORCE (NEWTONS)
400
200
0
-200
-400
20
25
30
35
40
45
50
Time (sec)


RIDGE MODELING for 1 5
POSITION (METERS)
10
8
6
4
2
0
20
25
30
35
40
45
50
Time (sec)

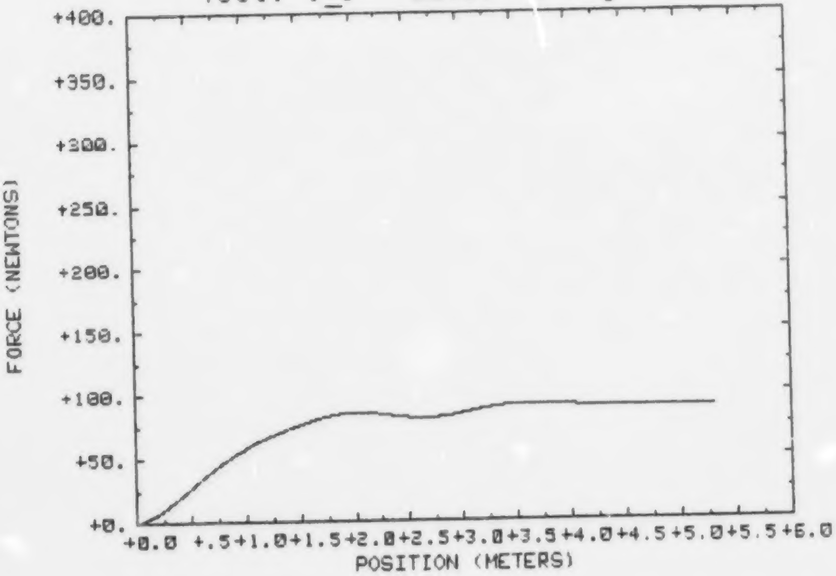

RIDGE MODELING
Project:3165C Test:1_5
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

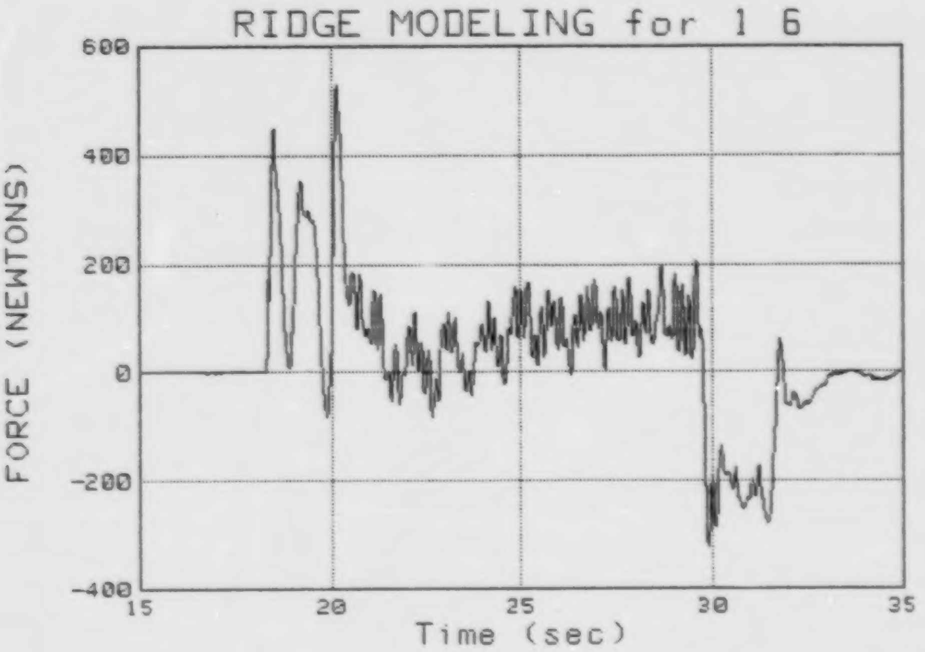

Ridge Modelling - Phase II
Test: 1_5 Date: 9 Aug 1989
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

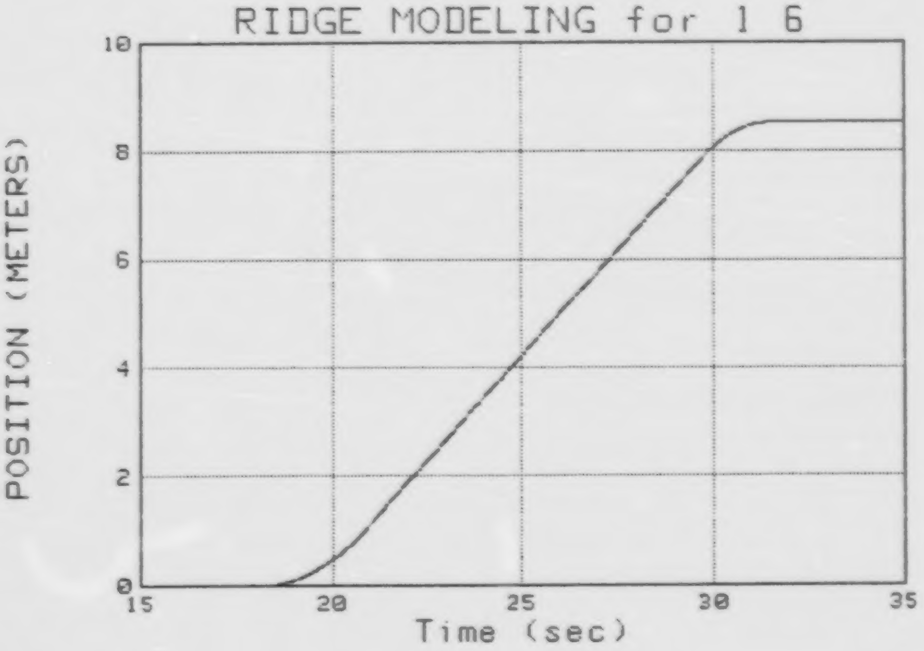
Ridge Modelling - Phase II
Test: 1_5 Date: 9 Aug 1989



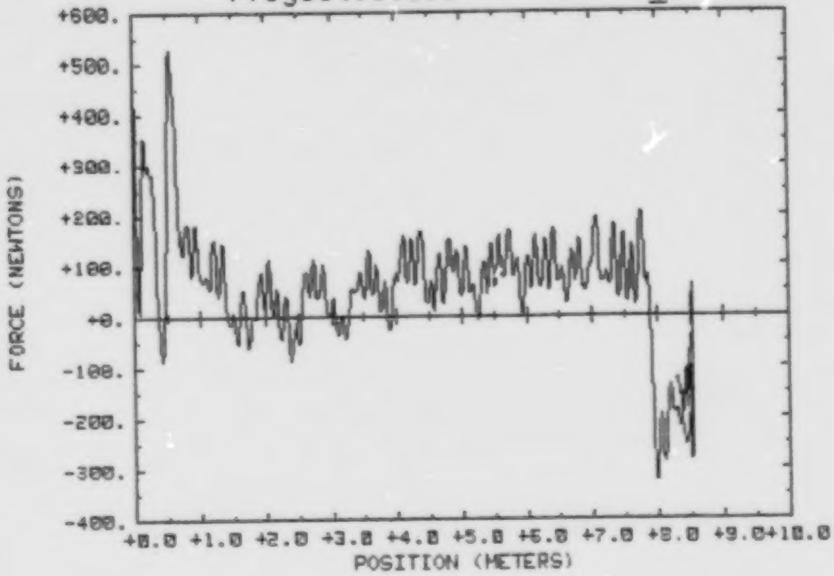
Ridge Modelling - Phase II
Test: 1_5 Date: 9 Aug 1989



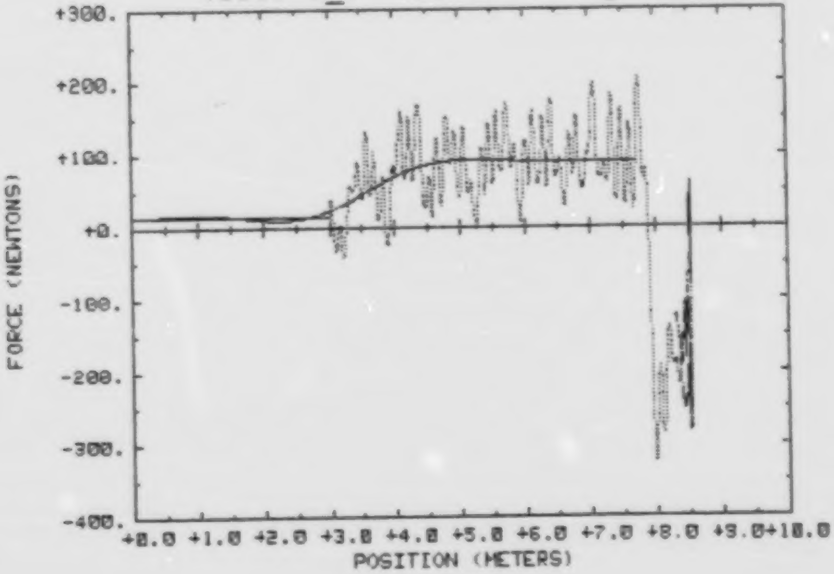

RIDGE MODELING for 1 6
FORCE (NEWTONS)
600
400
200
0
-200
-400
15
20
25
30
35
Time (sec)

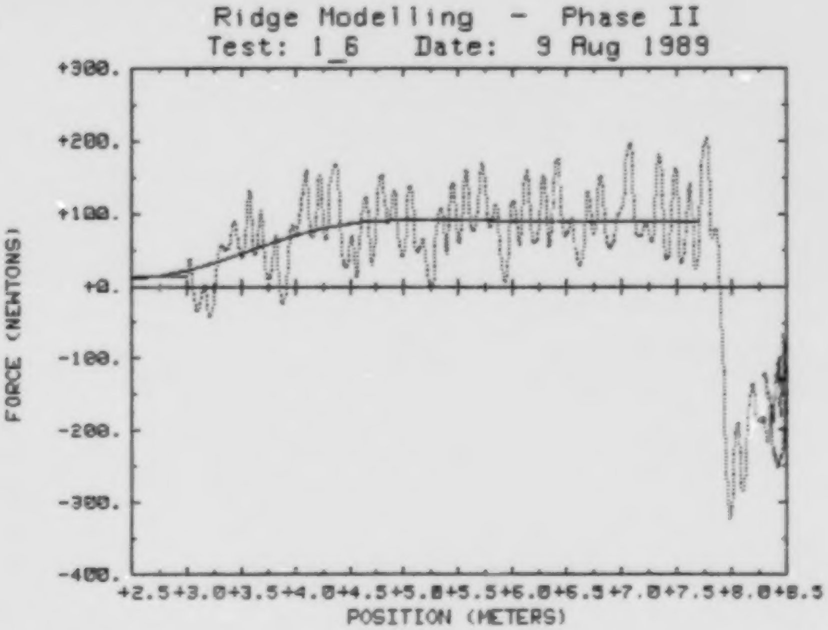

RIDGE MODELING for 1 6
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
Time (sec)

RIDGE MODELING
Project:3165C Test:1_6

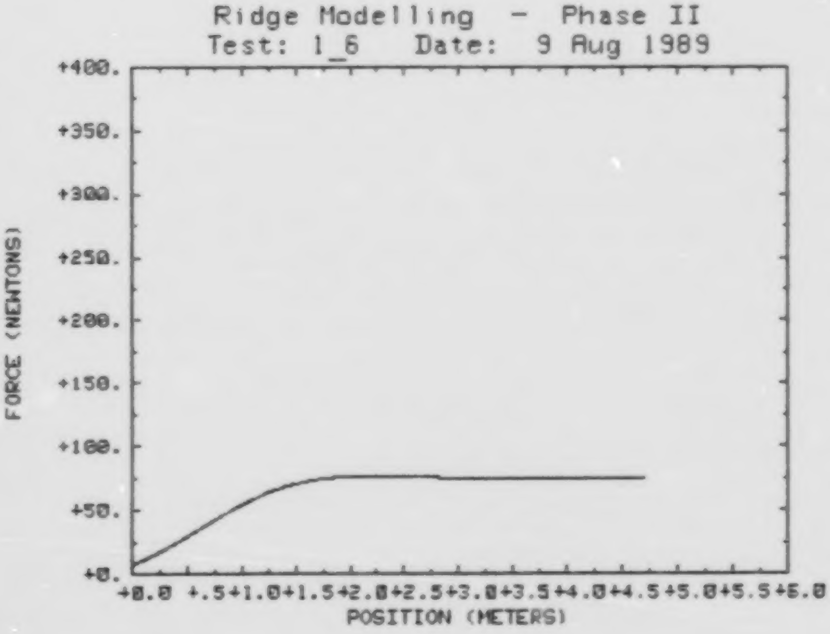


Ridge Modelling - Phase II
Test: 1_6 Date: 9 Aug 1989





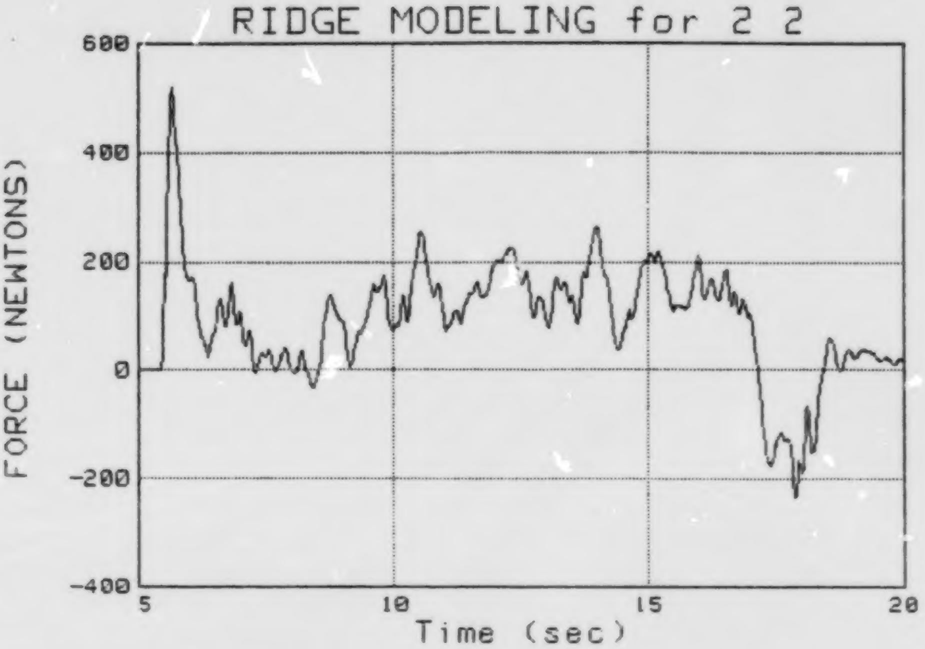
Ridge Modelling - Phase II
Test: 1_6 Date: 9 Aug 1989



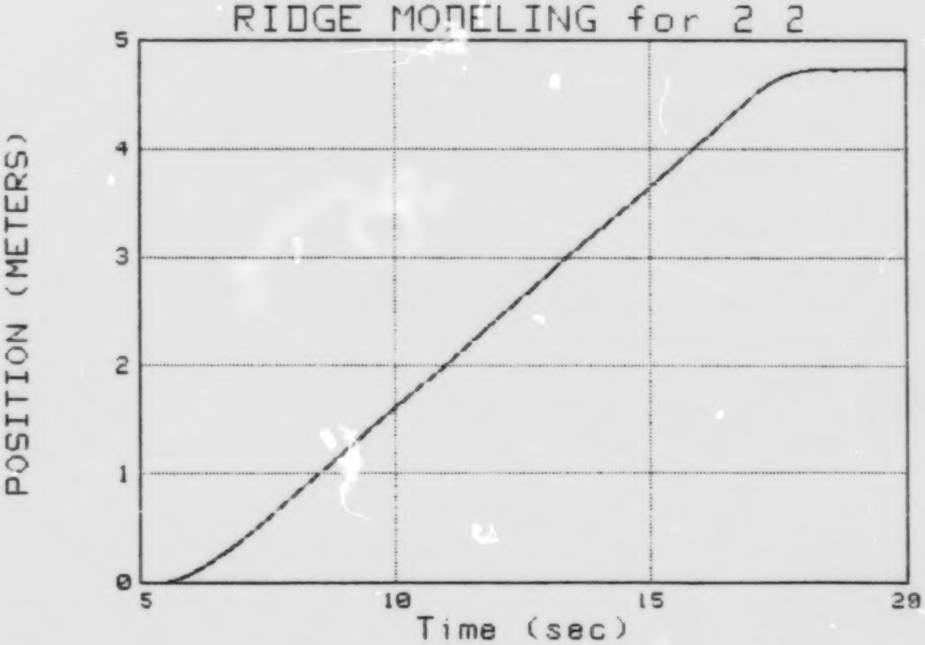
Ridge Modelling - Phase II
Test: 1_6 Date: 9 Aug 1989

APPENDIX B

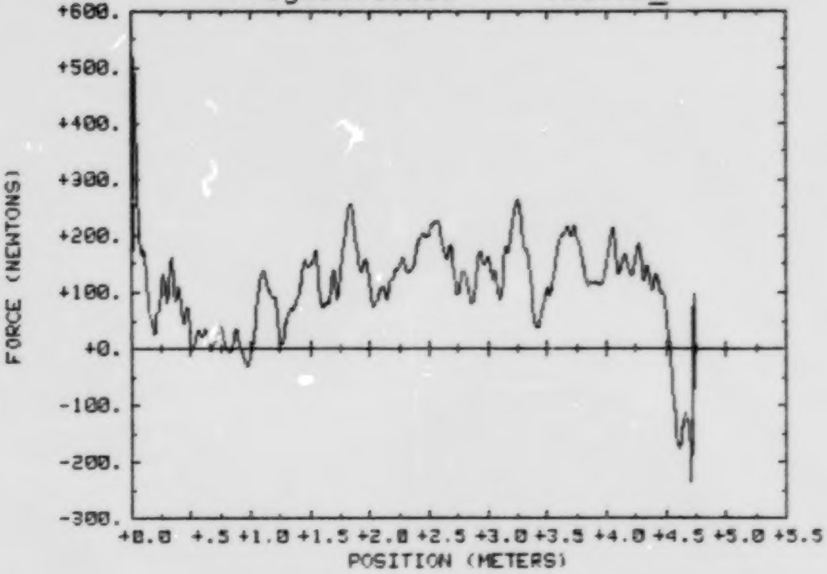
TEST DATA FOR SHEET #2



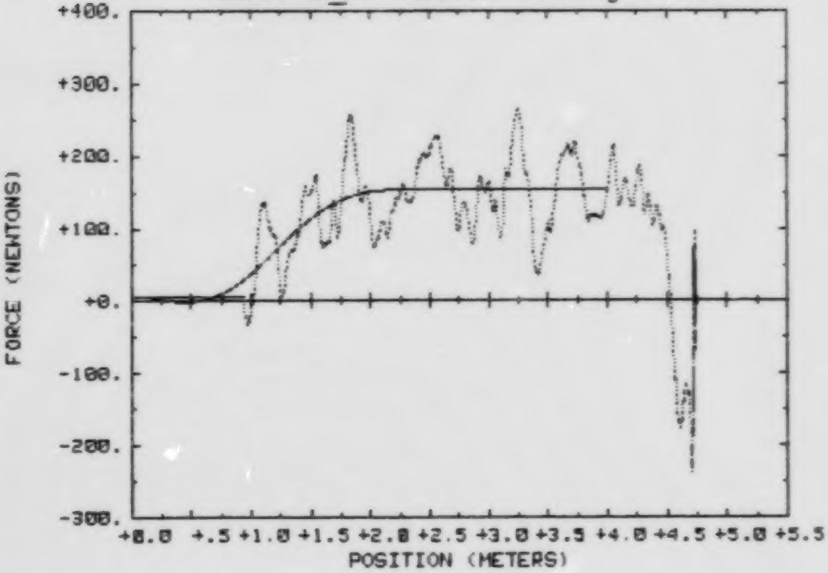
RIDGE MODELING for 2 2
FORCE (NEWTONS)
600
400
200
0
-200
-400
5
10
15
20
Time (sec)



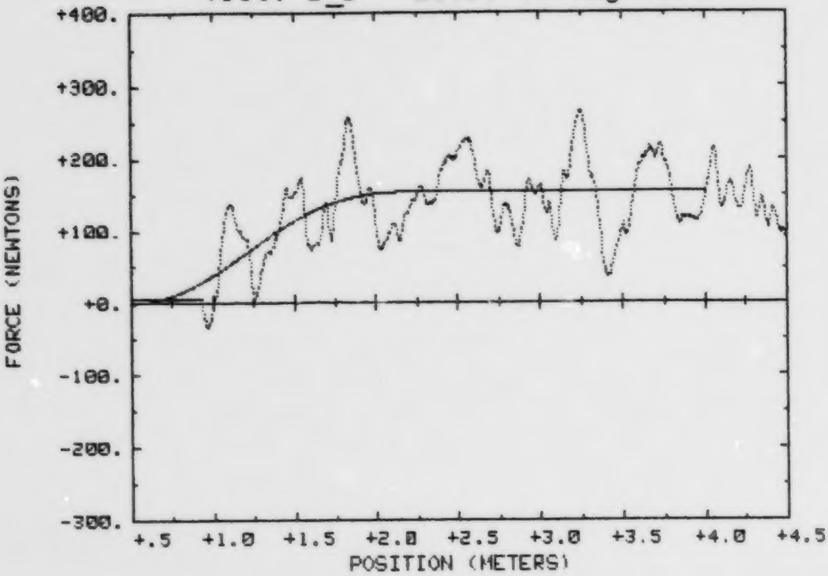
RIDGE MODELING for 2 2
POSITION (METERS)
5
4
3
2
1
0
5
10
15
20
Time (sec)



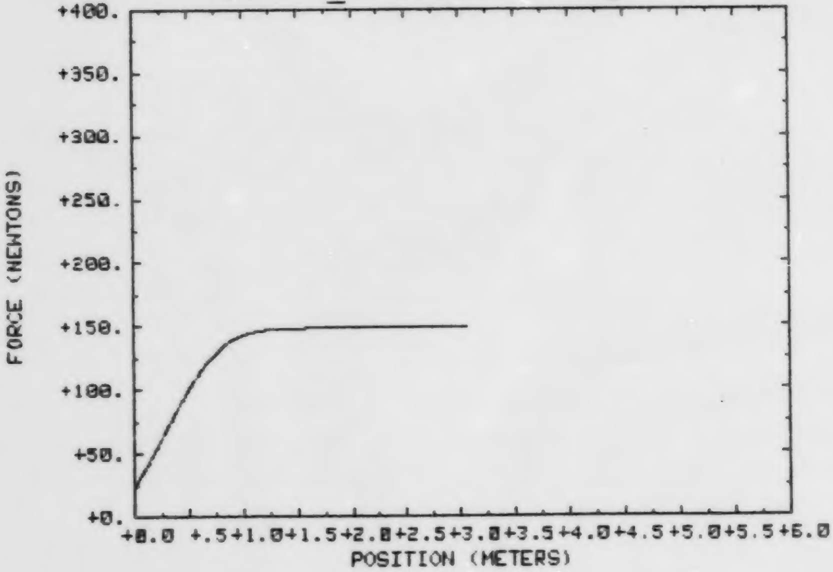
RIDGE MODELING
Project:3165C Test:2_2



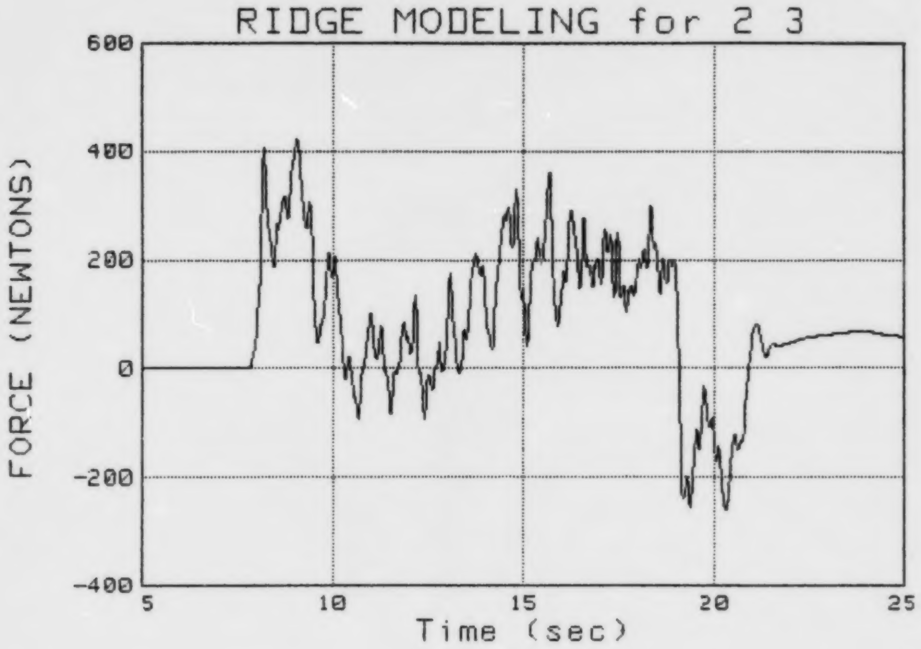
Ridge Modelling - Phase II
Test: 2_2 Date: 14 Aug 1989

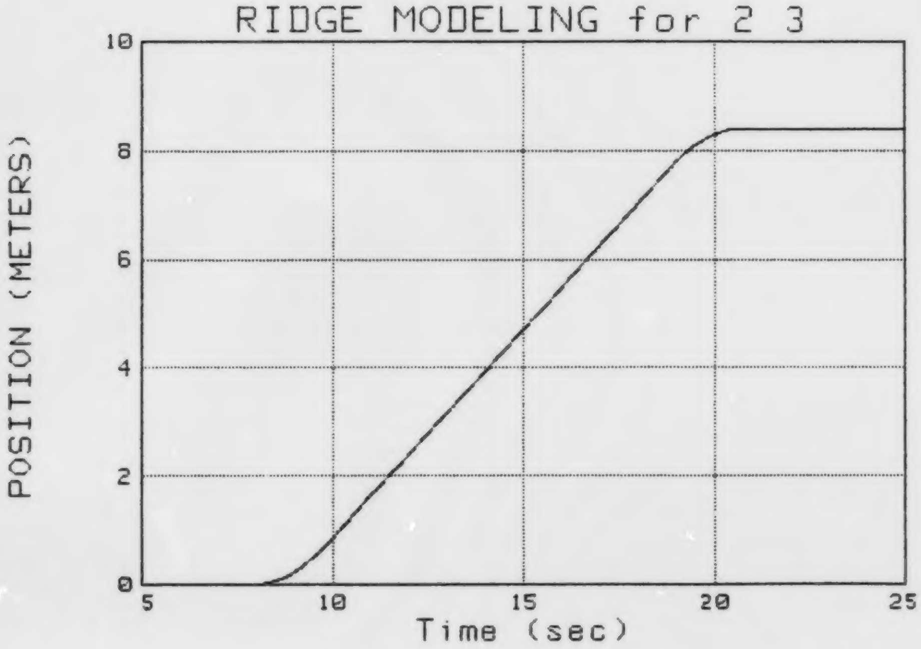


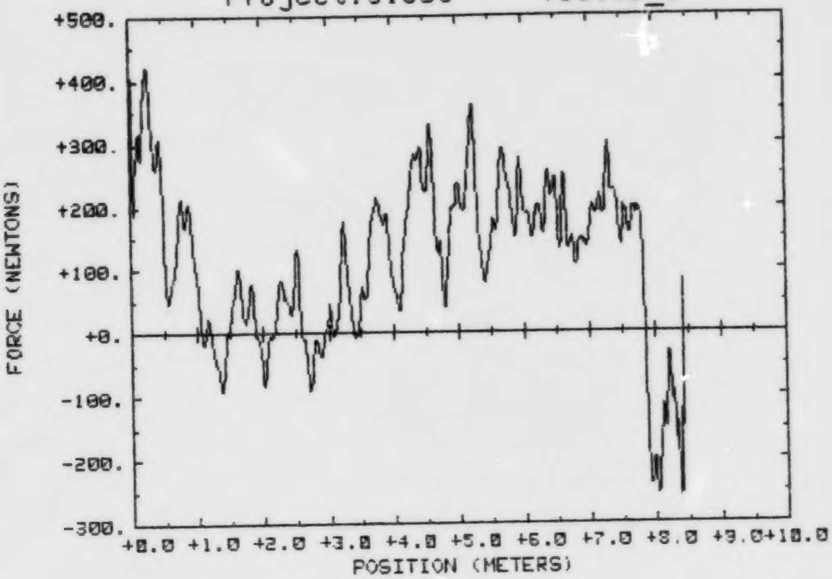
Ridge Modelling - Phase II
Test: 2_2 Date: 14 Aug 1989

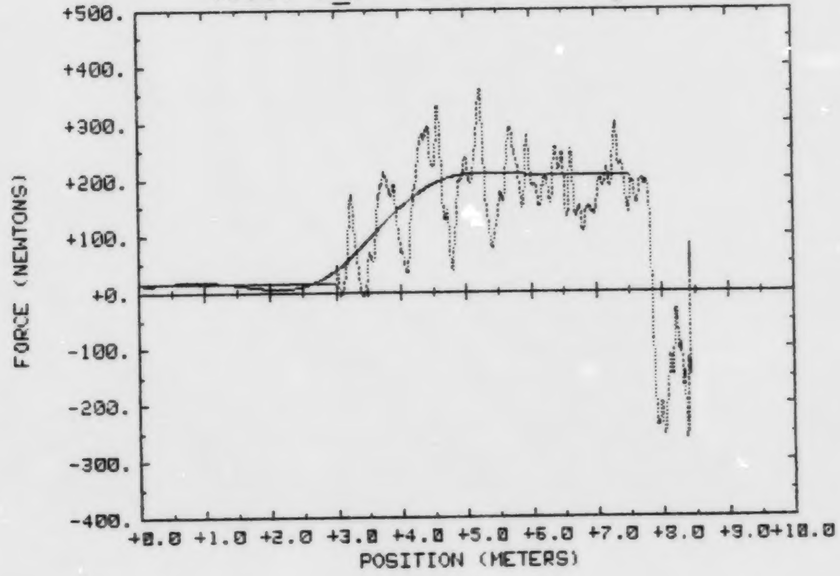


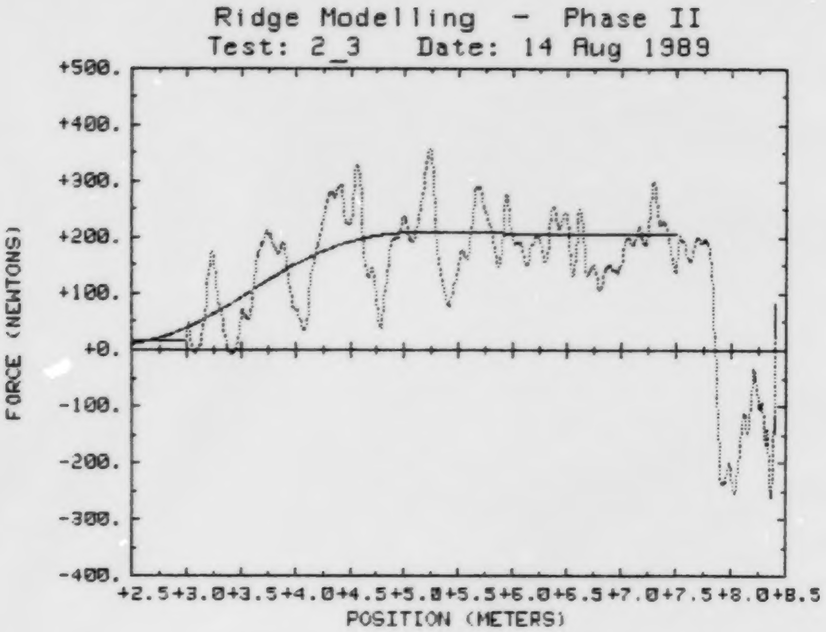
Ridge Modelling - Phase II
Test: 2_2 Date: 14 Aug 1989

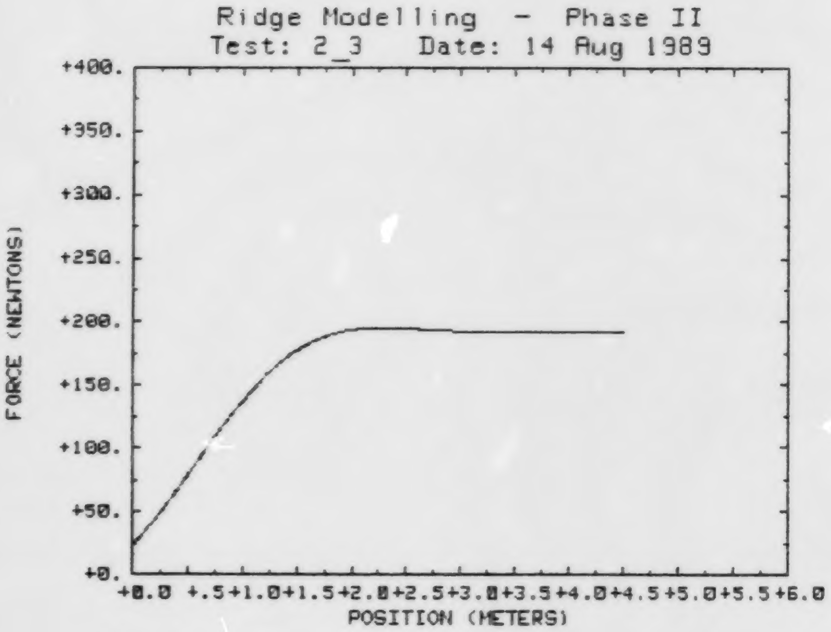

RIDGE MODELING for 2 3
FORCE (NEWTONS)
600
400
200
0
-200
-400
5
10
15
20
25
Time (sec)

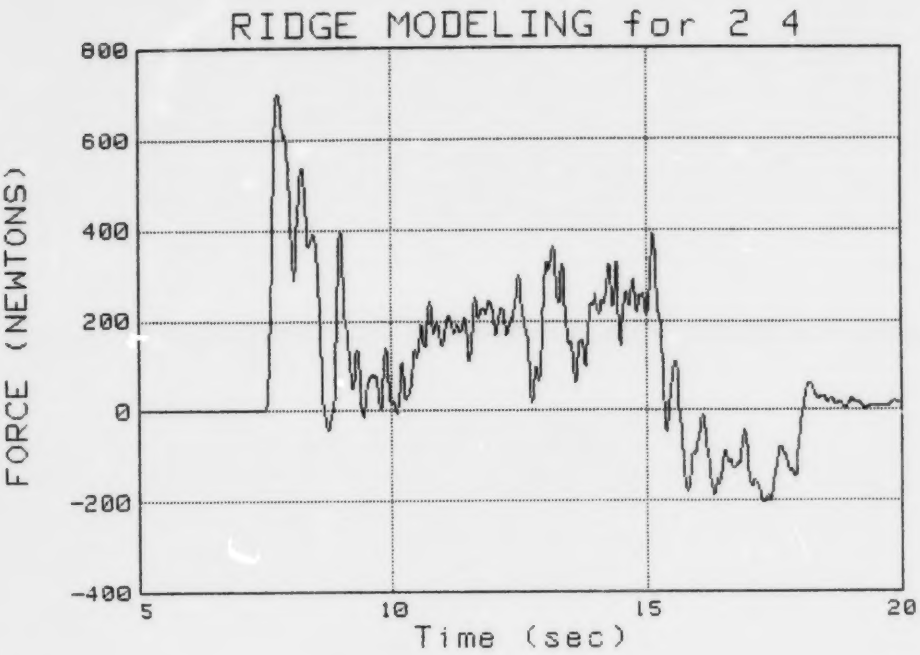

RIDGE MODELING for 2 3
POSITION (METERS)
10
8
6
4
2
0
5
10
15
20
25
Time (sec)


RIDGE MODELING
Project:3165C Test:2_3

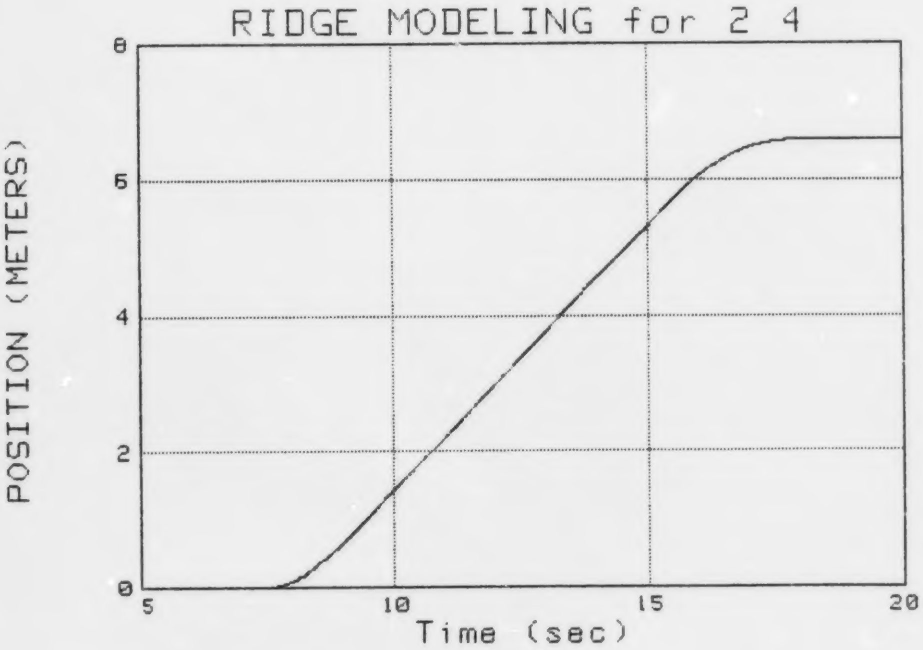

Ridge Modelling - Phase II
Test: 2_3 Date: 14 Aug 1989


Ridge Modelling - Phase II
Test: 2_3 Date: 14 Aug 1989
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
FORCE (NEWTONS)
+2.5+3.0+3.5+4.0+4.5+5.0+5.5+6.0+6.5+7.0+7.5+8.0+8.5
POSITION (METERS)

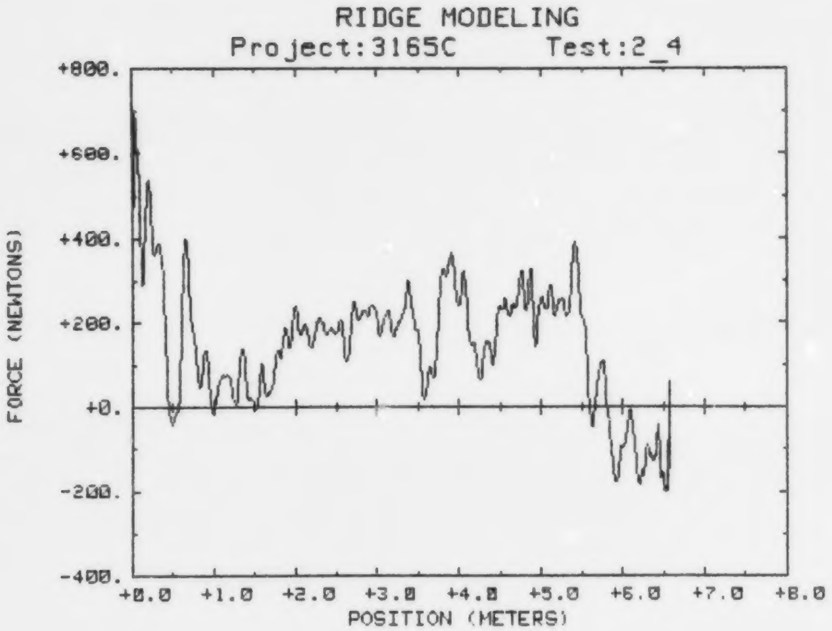

Ridge Modelling - Phase II
Test: 2_3 Date: 14 Aug 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0 +.5+1.0+1.5+2.0+2.5+3.0+3.5+4.0+4.5+5.0+5.5+6.0
POSITION (METERS)

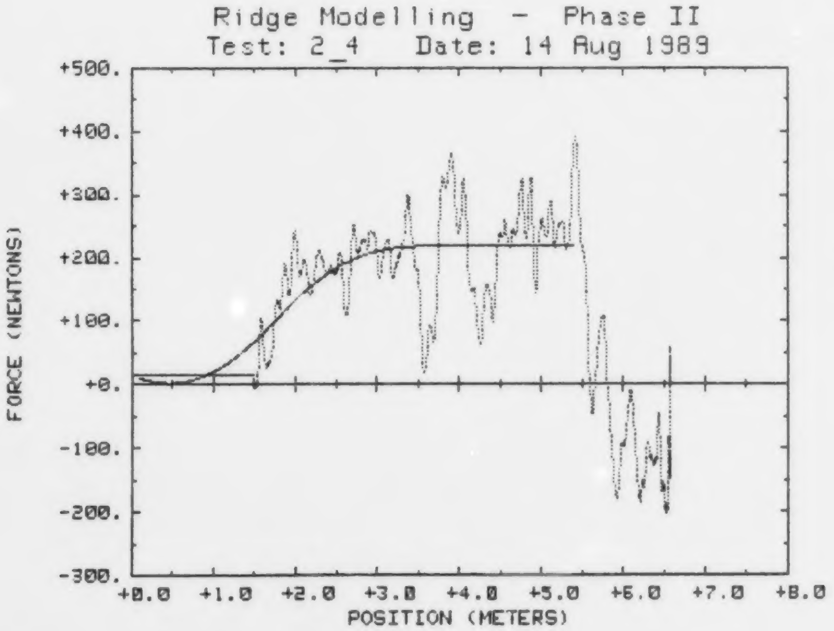


RIDGE MODELING for 2 4

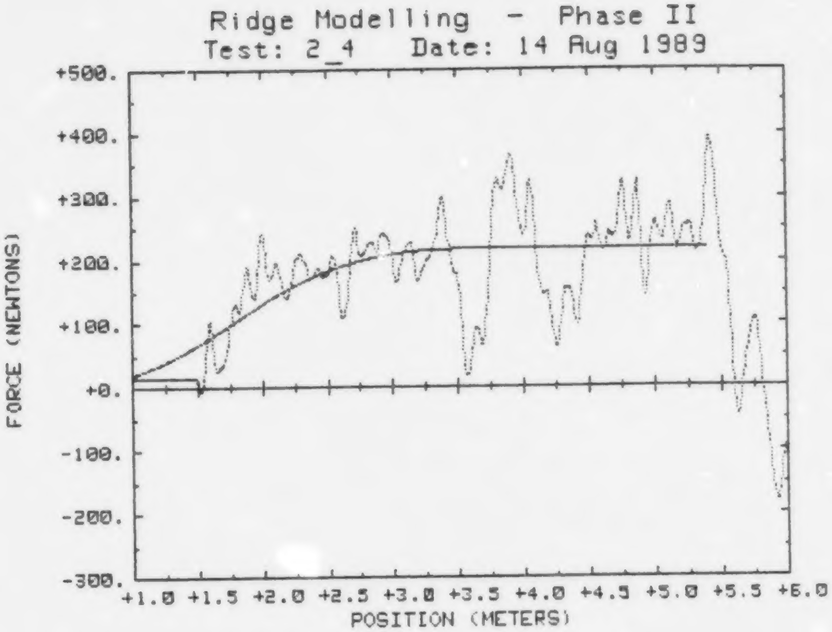


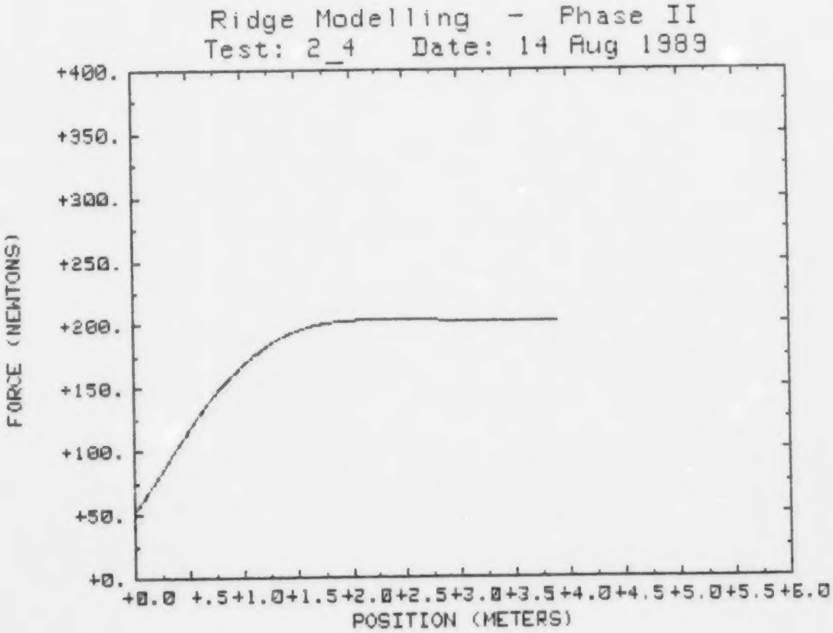
RIDGE MODELING for 2 4

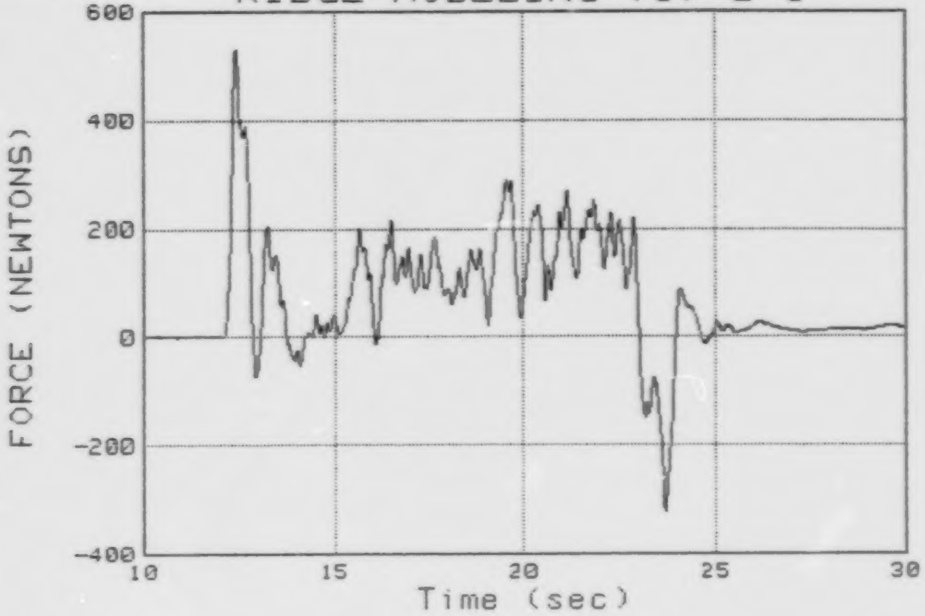

RIDGE MODELING
Project:3165C Test:2_4
+800.
+600.
+400.
+200.
+0.
-200.
-400.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 2_4 Date: 14 Aug 1989
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
POSITION (METERS)

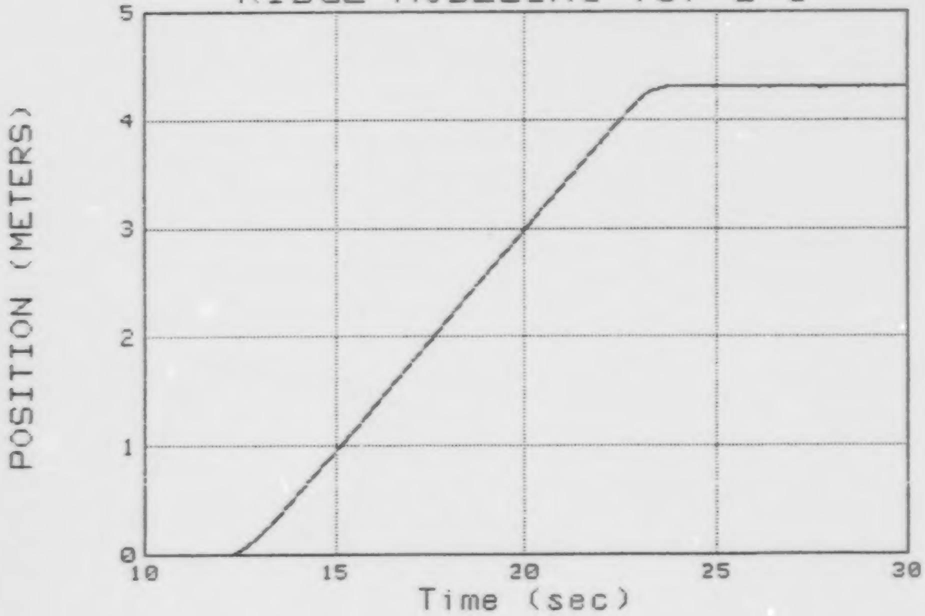
X


Ridge Modelling - Phase II
Test: 2_4 Date: 14 Aug 1989

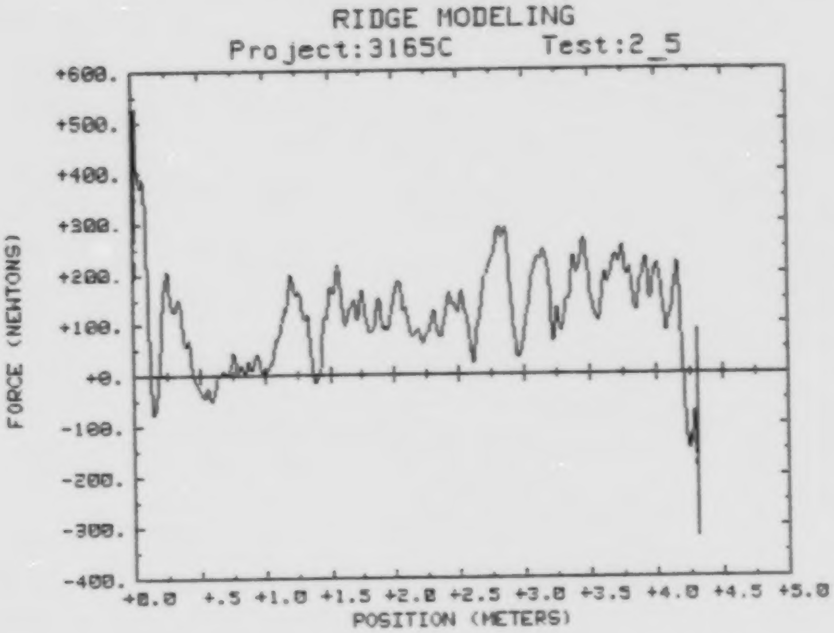

Ridge Modelling - Phase II
Test: 2_4 Date: 14 Aug 1989

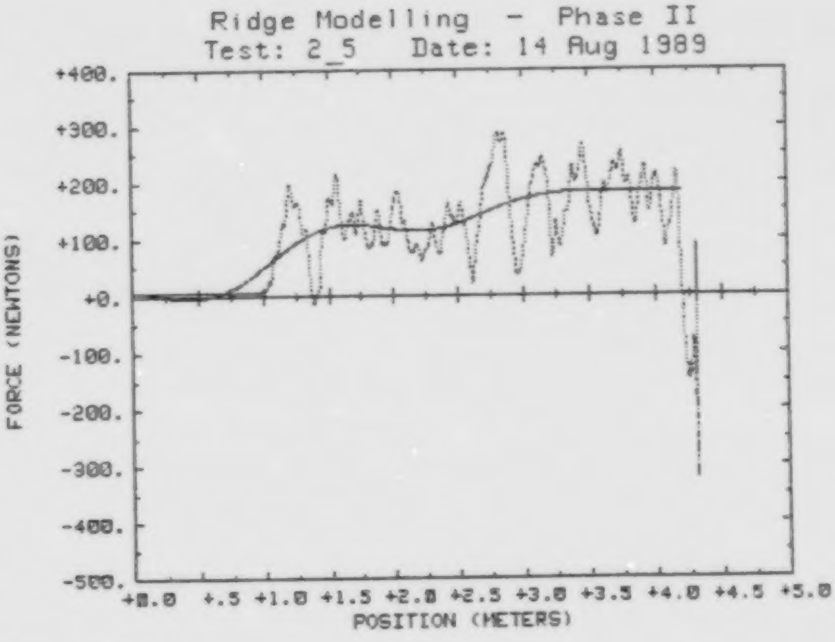


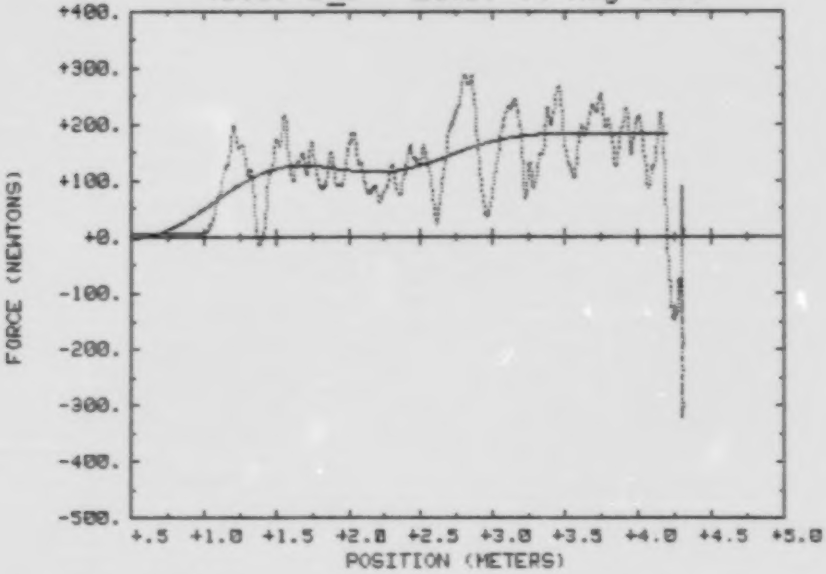
RIDGE MODELING for 2 5



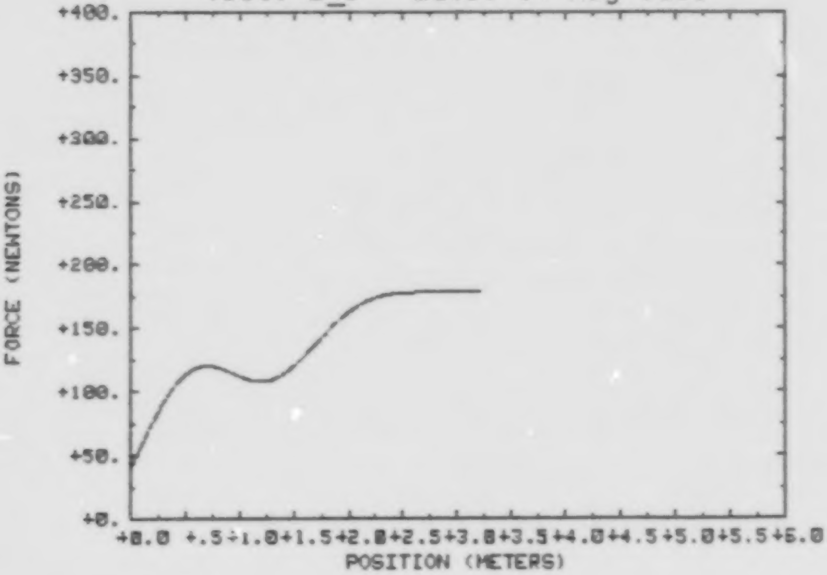
RIDGE MODELING for 2 5


RIDGE MODELING
Project:3165C Test:2_5
+600.
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
POSITION (METERS)

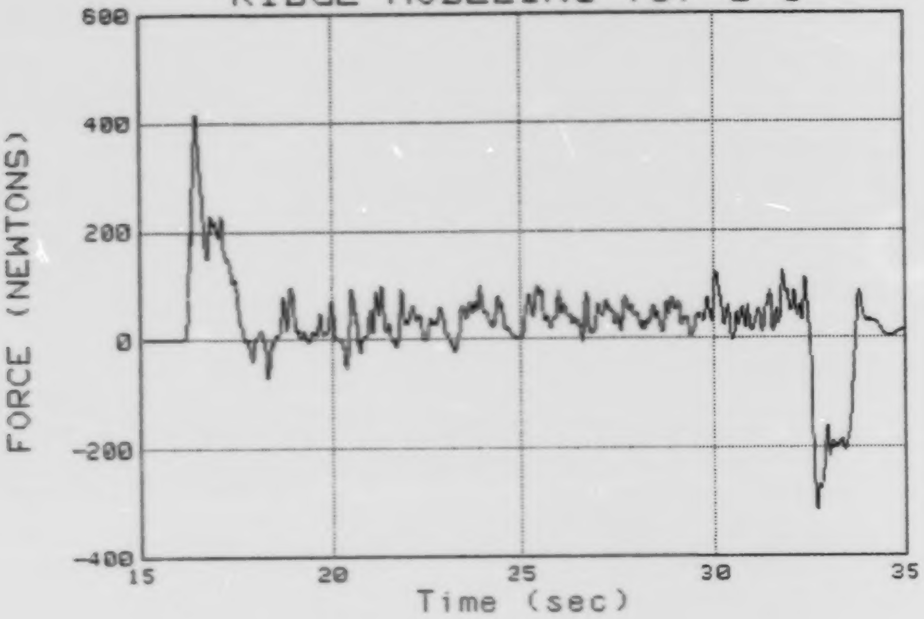

Ridge Modelling - Phase II
Test: 2_5 Date: 14 Aug 1989
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
POSITION (METERS)



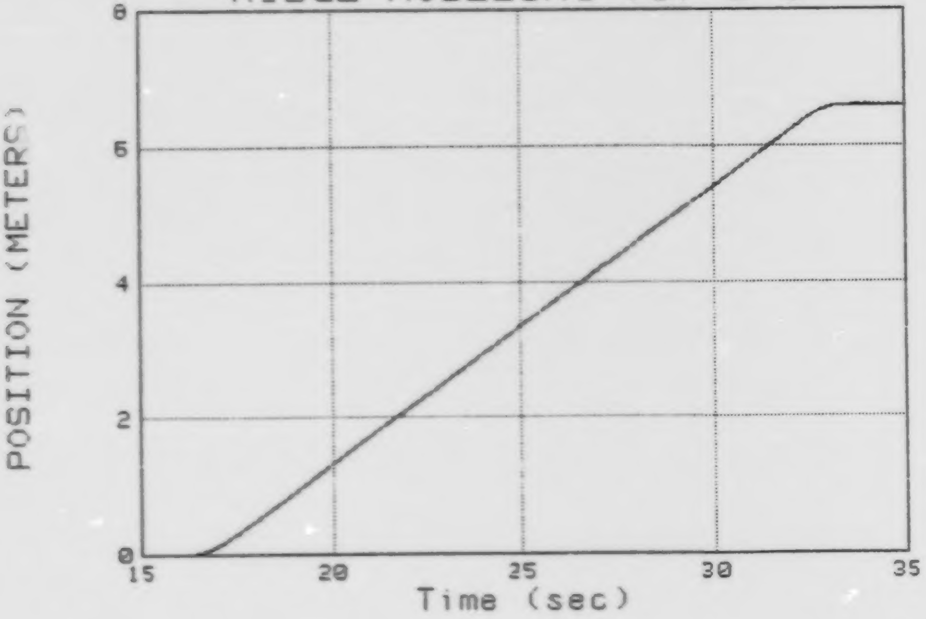
Ridge Modelling - Phase II
Test: 2_5 Date: 14 Aug 1989



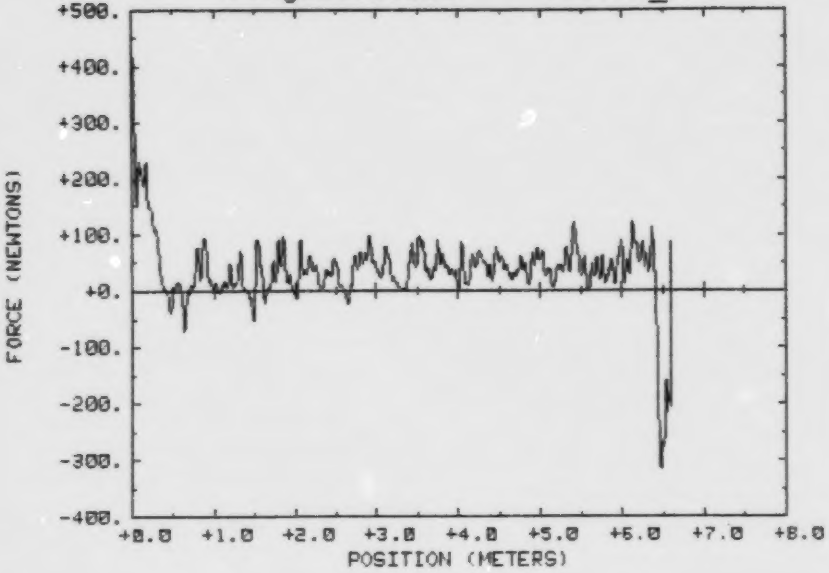
Ridge Modelling - Phase II
Test: 2_5 Date: 14 Aug 1989



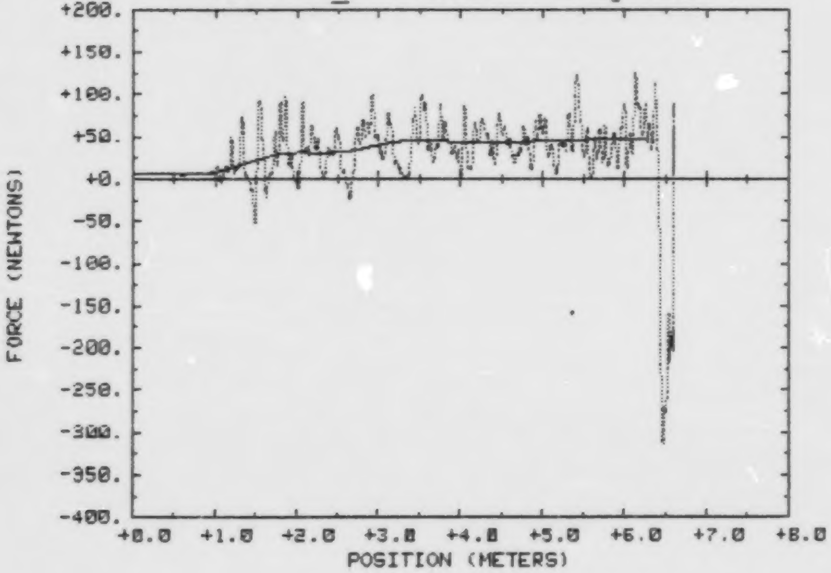
RIDGE MODELING for 2 6



RIDGE MODELING for 2 6

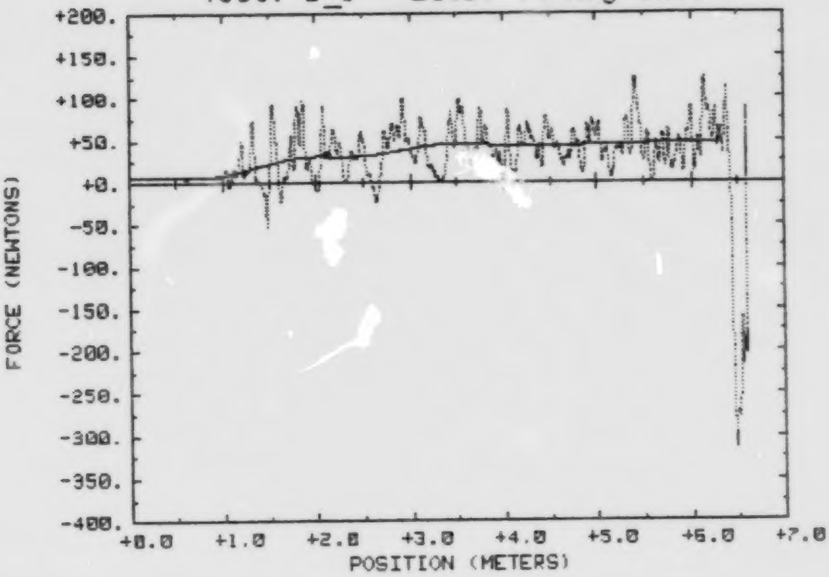


RIDGE MODELING
Project:3165C Test:2_6

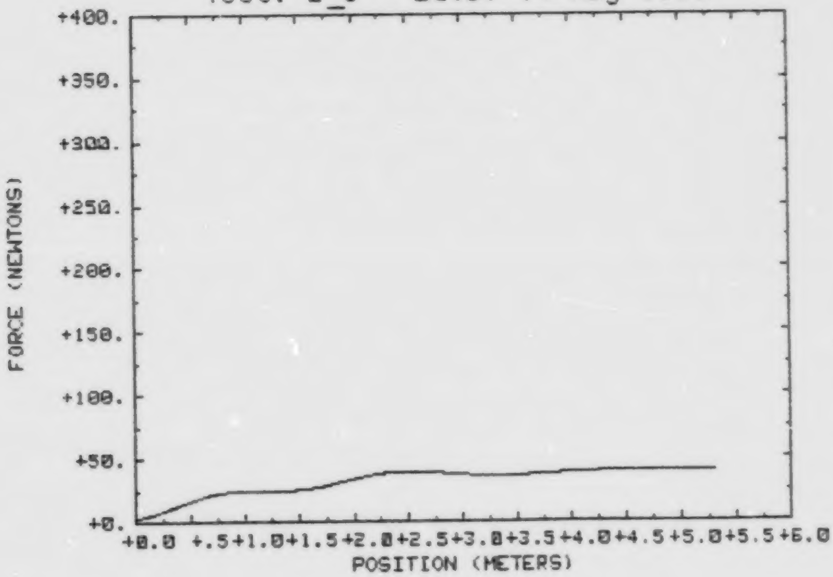


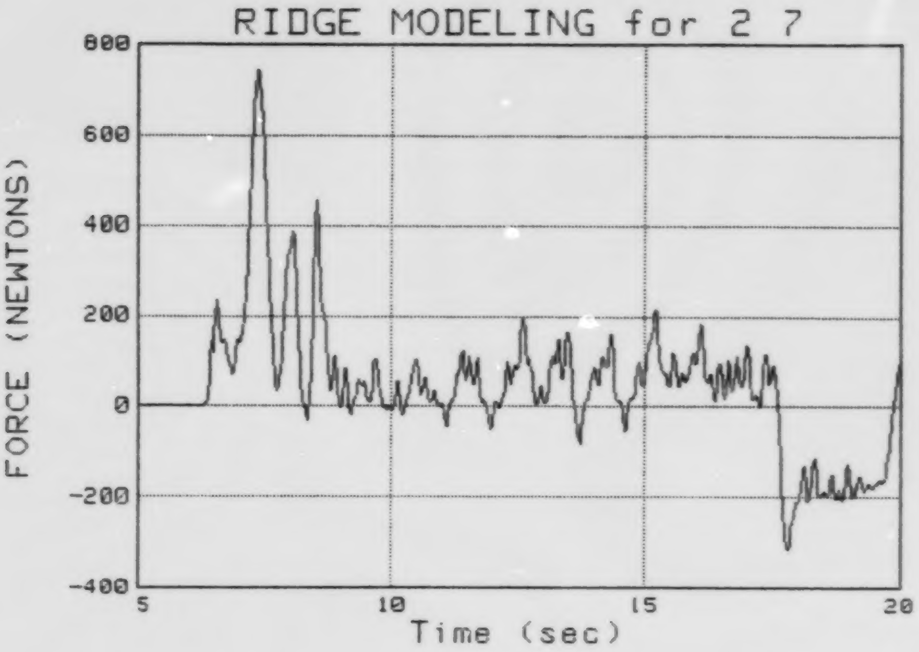
Ridge Modelling - Phase II
Test: 2_6 Date: 14 Aug 1989

Ridge Modelling - Phase II
Test: 2_6 Date: 14 Aug 1989

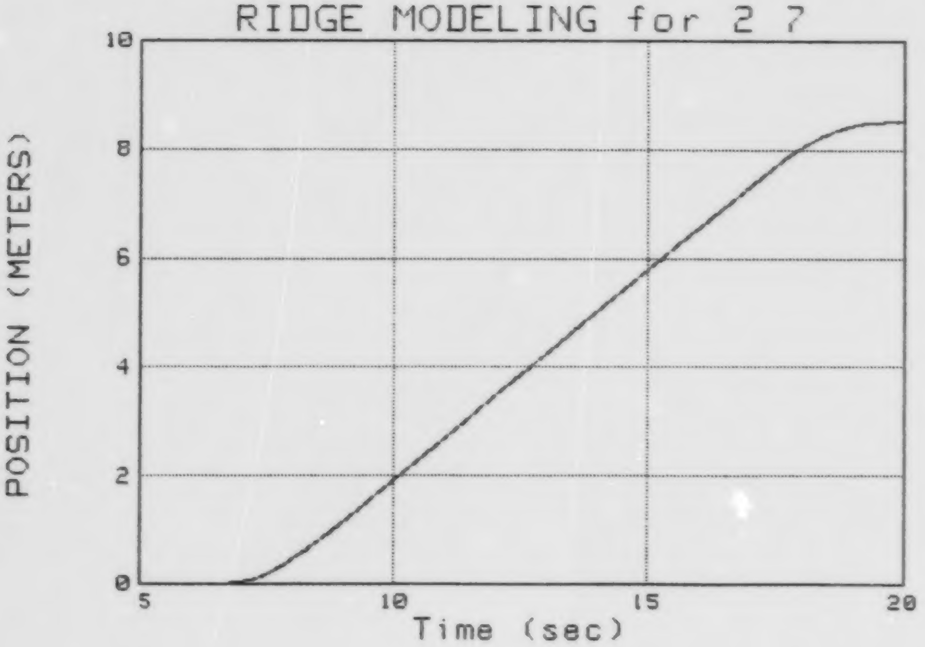


Ridge Modelling - Phase II
Test: 2_6 Date: 14 Aug 1989

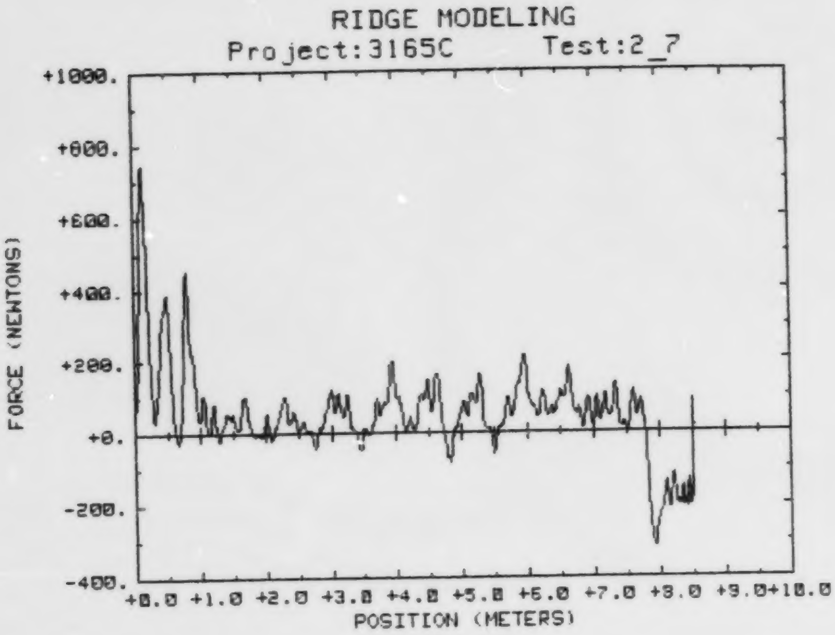


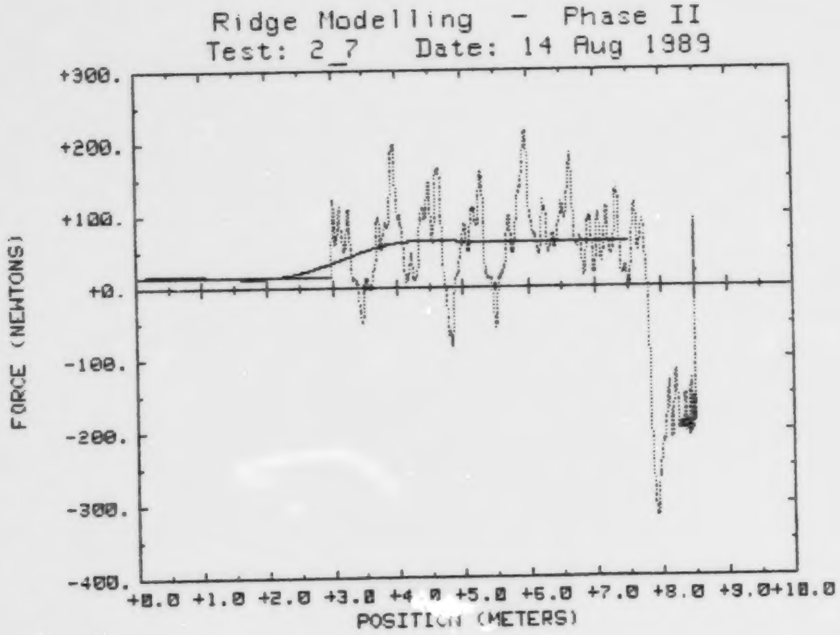


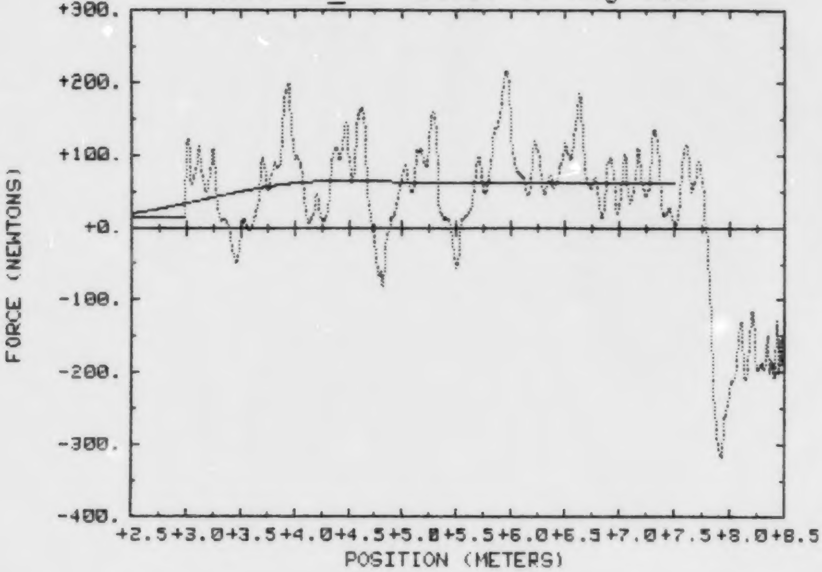
RIDGE MODELING for 2 7

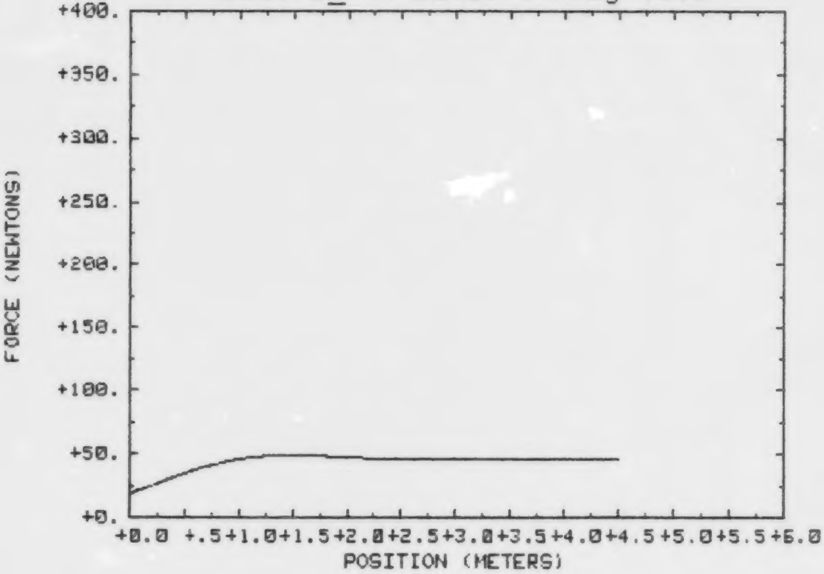


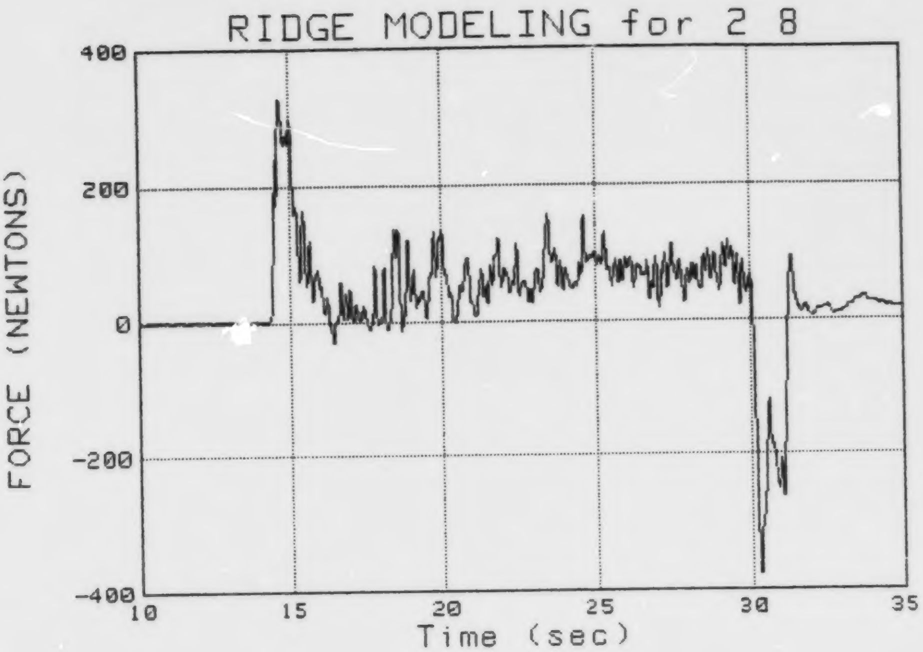
RIDGE MODELING for 2 7

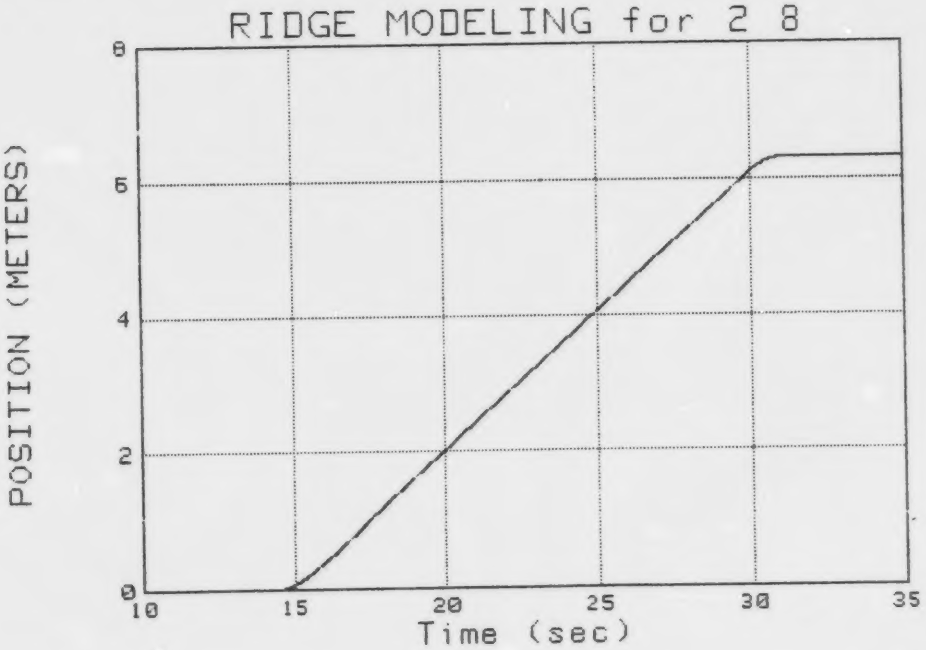

RIDGE MODELING
Project:3165C Test:2_7
FORCE (NEWTONS)
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)

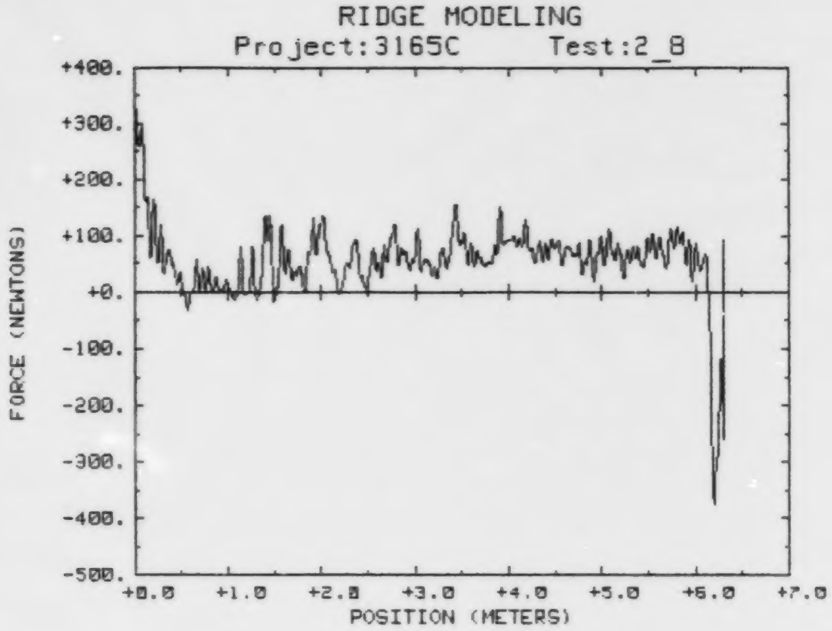

Ridge Modelling - Phase II
Test: 2_7 Date: 14 Aug 1989
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)

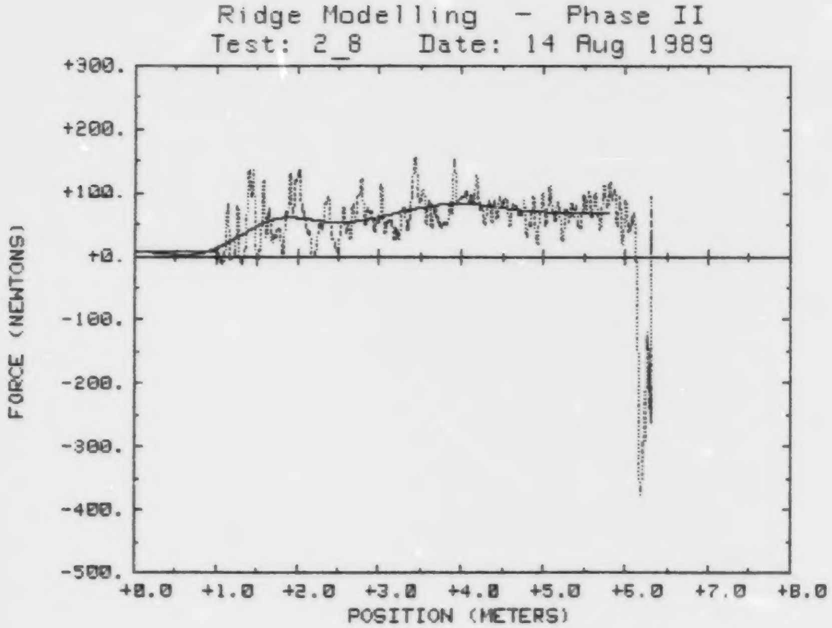

Ridge Modelling - Phase II
Test: 2_7 Date: 14 Aug 1989

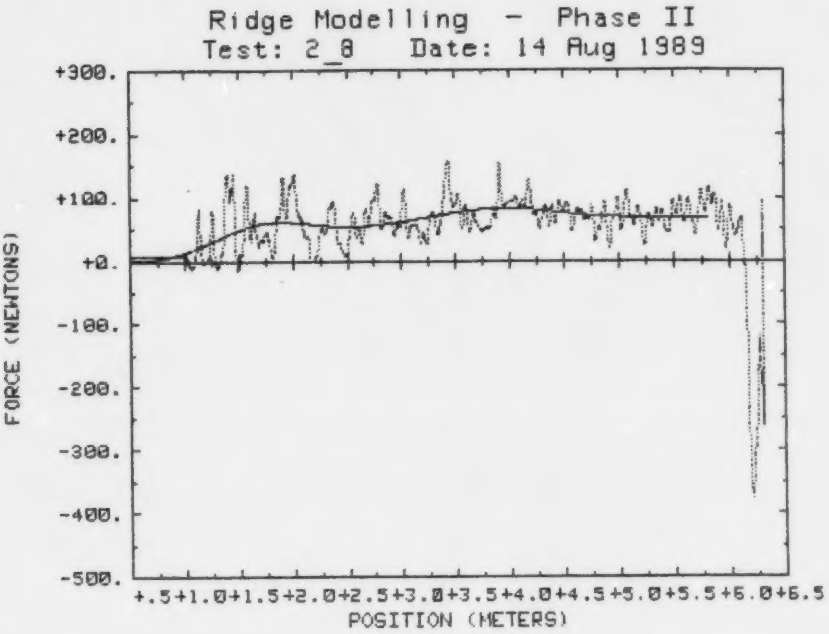

Ridge Modelling - Phase II
Test: 2_7 Date: 14 Aug 1989

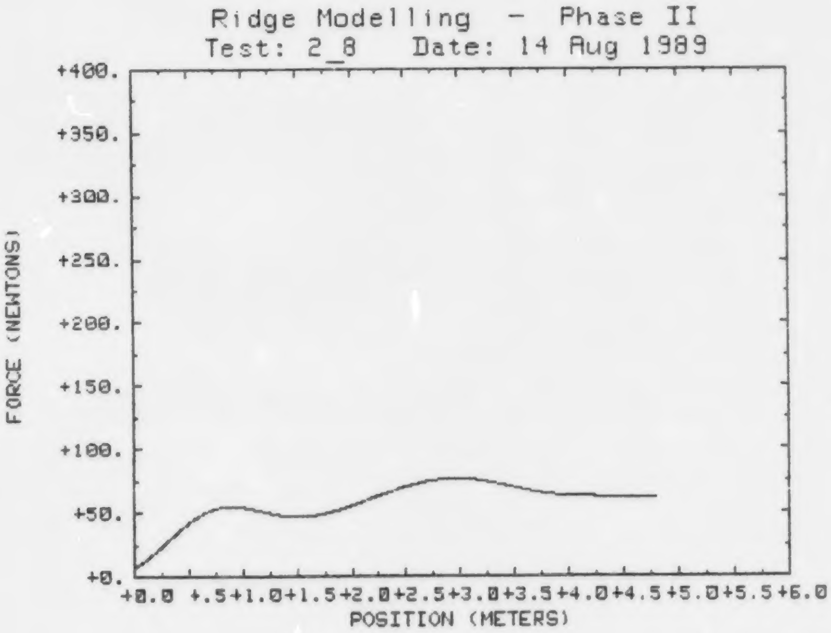

RIDGE MODELING for 2 8

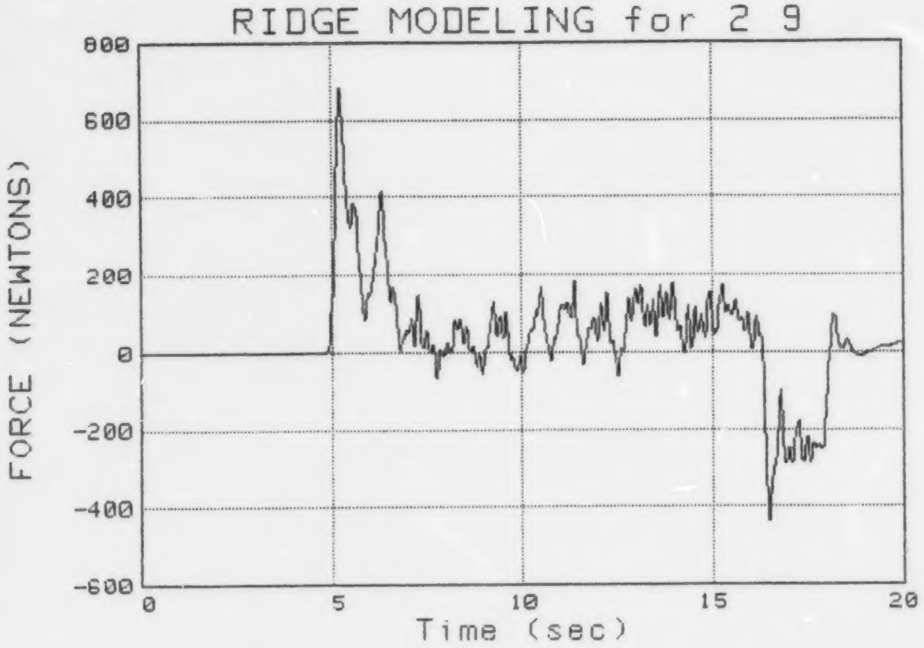

RIDGE MODELING for 2 8

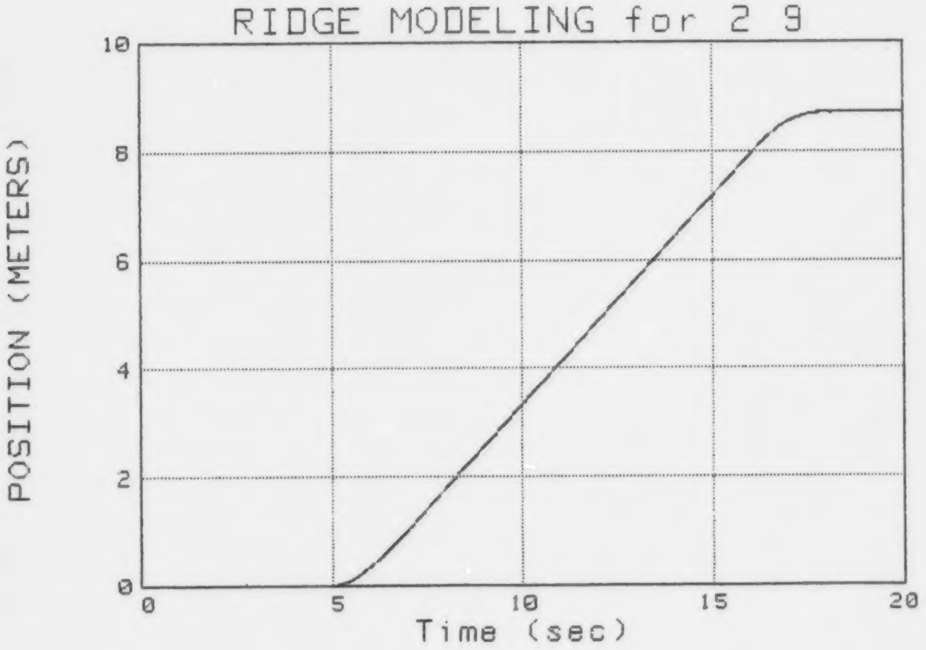

RIDGE MODELING
Project:3165C Test:2_8
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 2_8 Date: 14 Aug 1989
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 2_8 Date: 14 Aug 1989
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
FORCE (NEWTONS)
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
+6.5
POSITION (METERS)

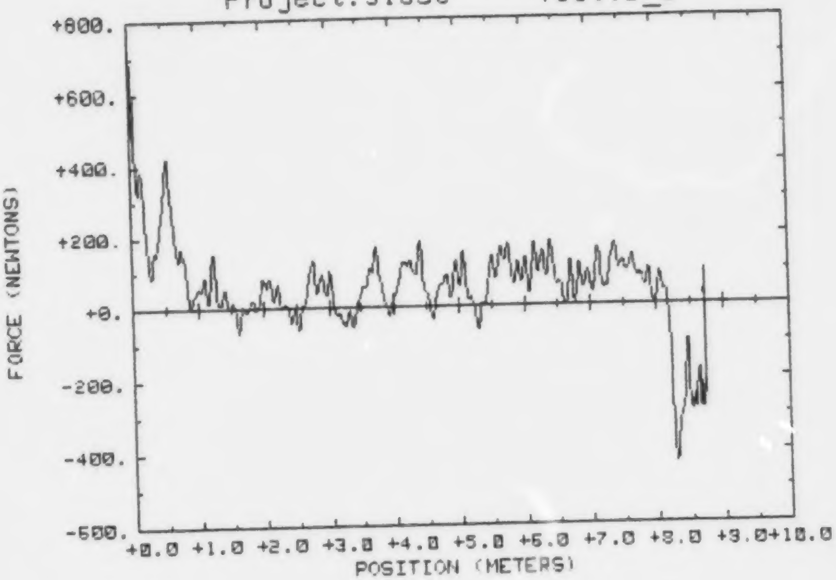

Ridge Modelling - Phase II
Test: 2_8 Date: 14 Aug 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)


RIDGE MODELING for 2 9
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
-600
0
5
10
15
20
Time (sec)

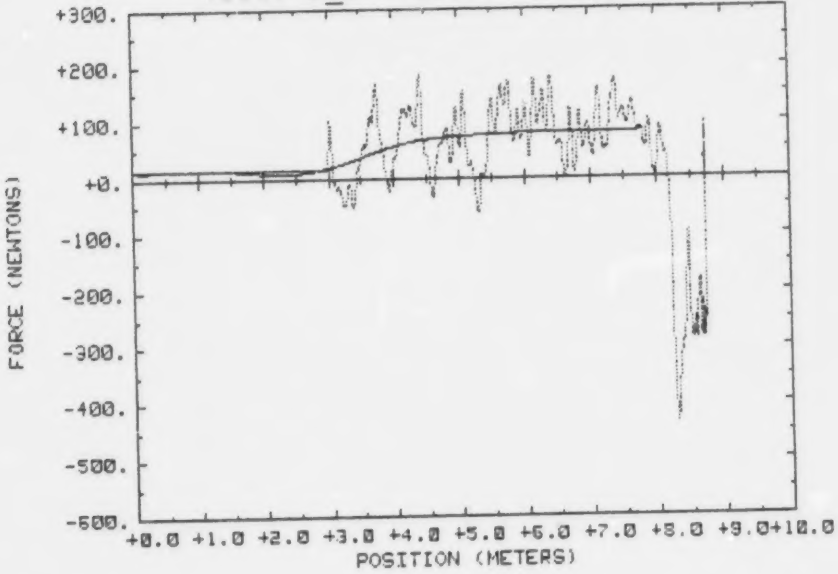

RIDGE MODELING for 2 9
POSITION (METERS)
10
8
6
4
2
0
0
5
10
15
20
Time (sec)

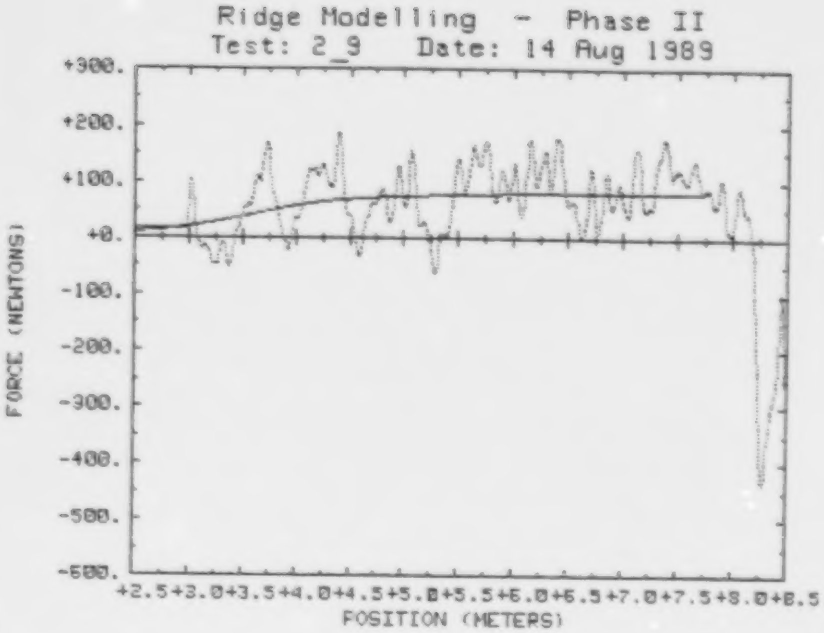
X

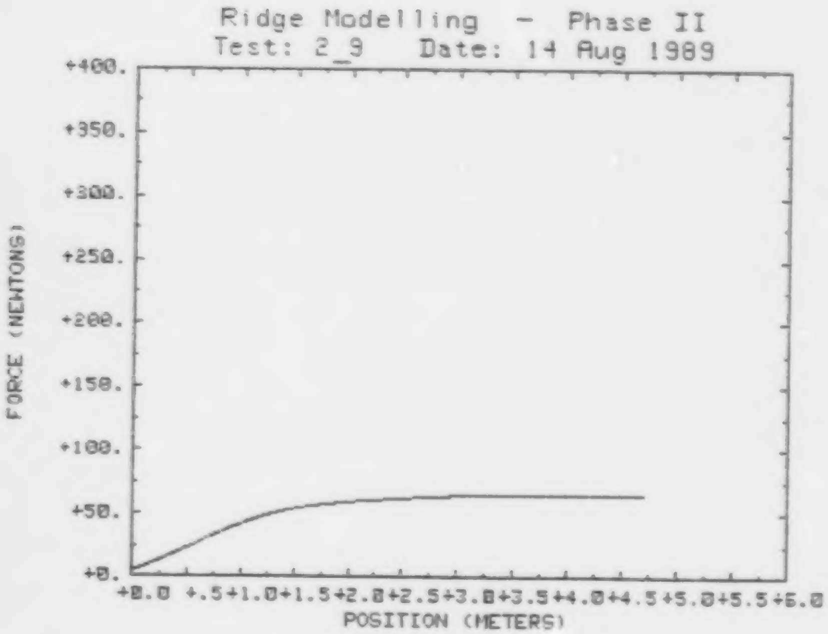
RIDGE MODELING
Project:3165C Test:2_9

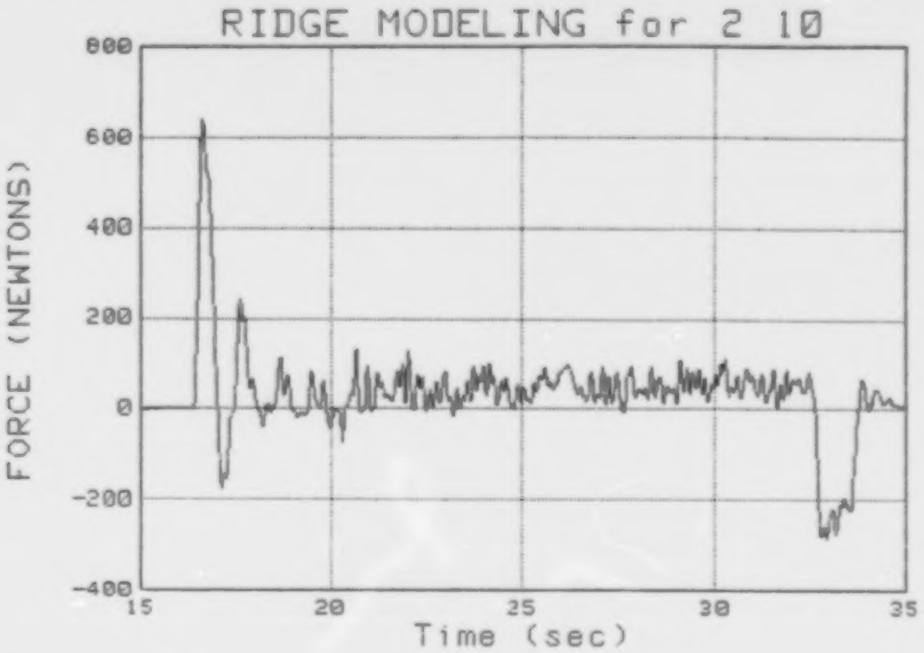


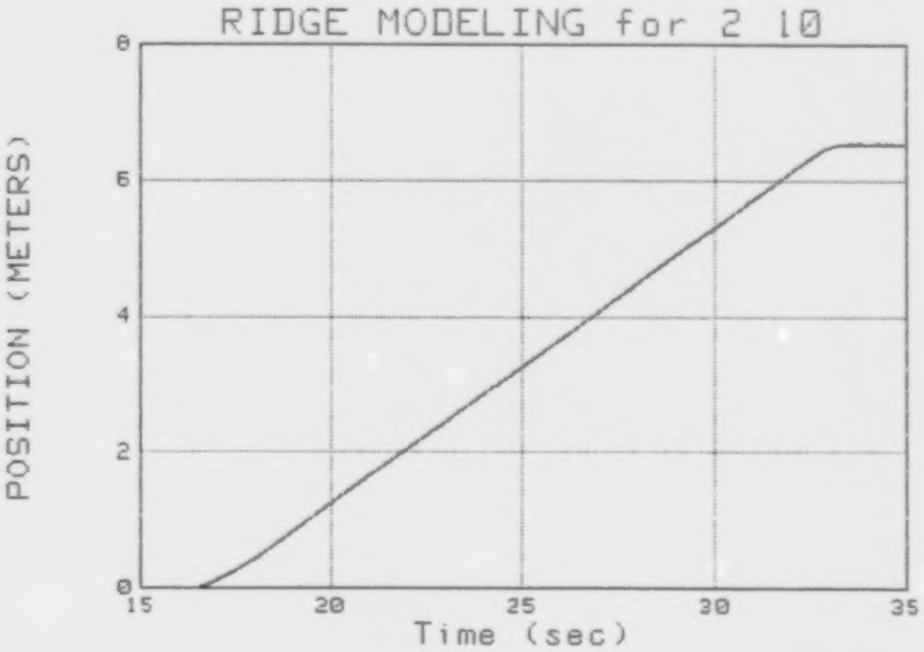
Ridge Modelling - Phase II
Test: 2_9 Date: 14 Aug 1989

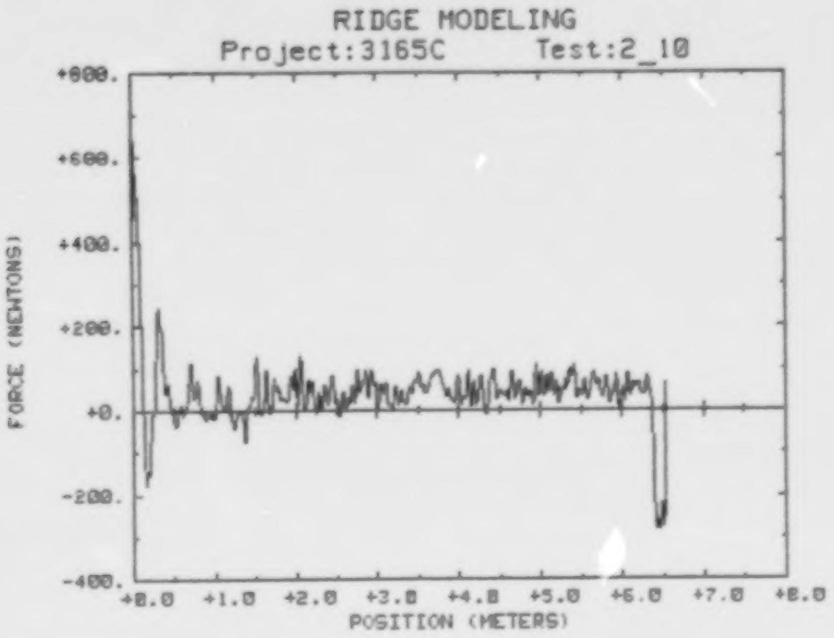


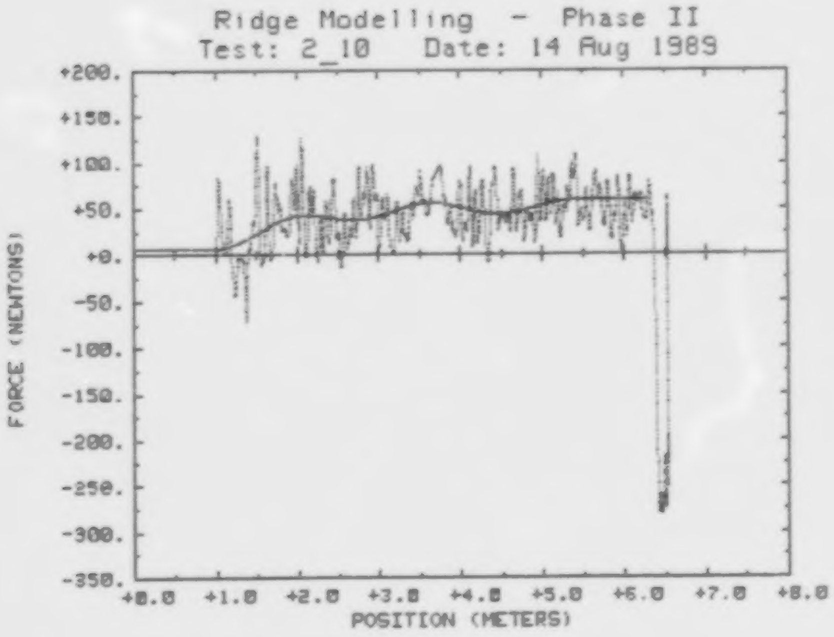

Ridge Modelling - Phase II
Test: 2_9 Date: 14 Aug 1989
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
FORCE (NEWTONS)
+2.5+3.0+3.5+4.0+4.5+5.0+5.5+6.0+6.5+7.0+7.5+8.0+8.5
POSITION (METERS)

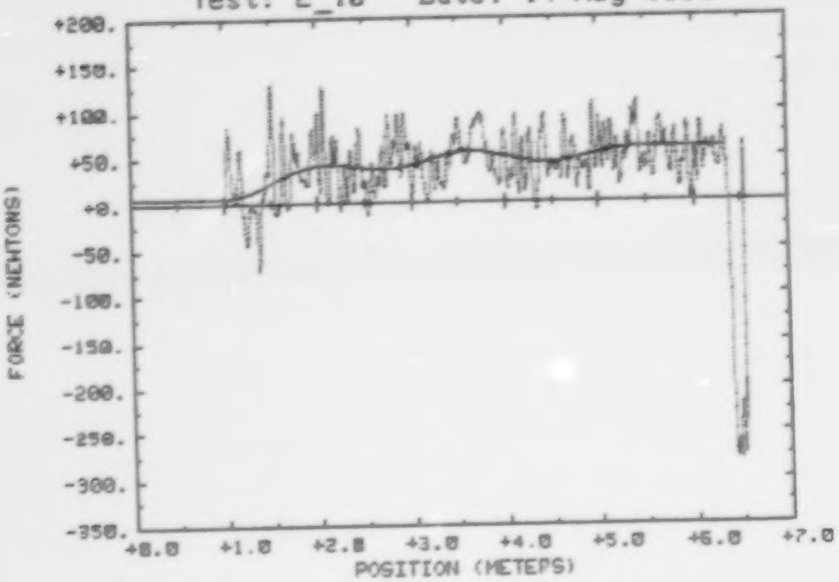

Ridge Modelling - Phase II
Test: 2_9 Date: 14 Aug 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0 +.5+1.0+1.5+2.0+2.5+3.0+3.5+4.0+4.5+5.0+5.5+6.0
POSITION (METERS)

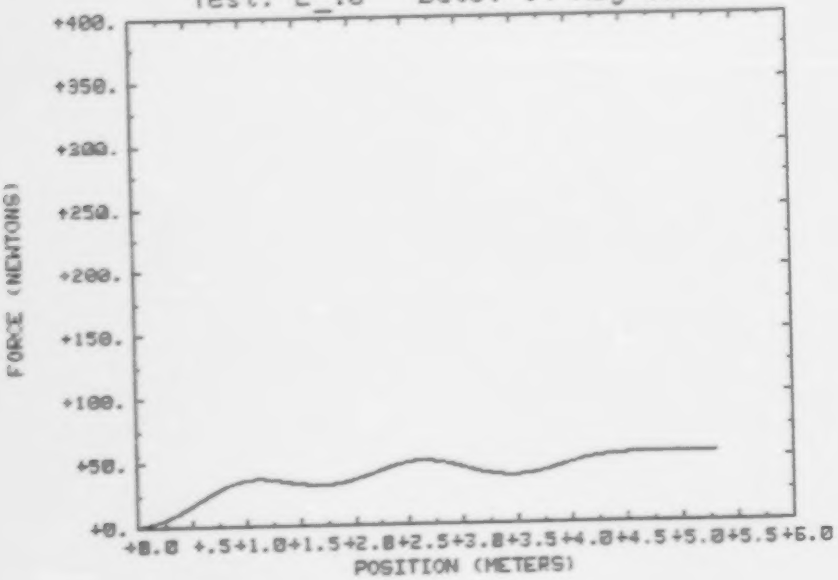

RIDGE MODELING for 2 10
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
15
20
25
30
35
Time (sec)

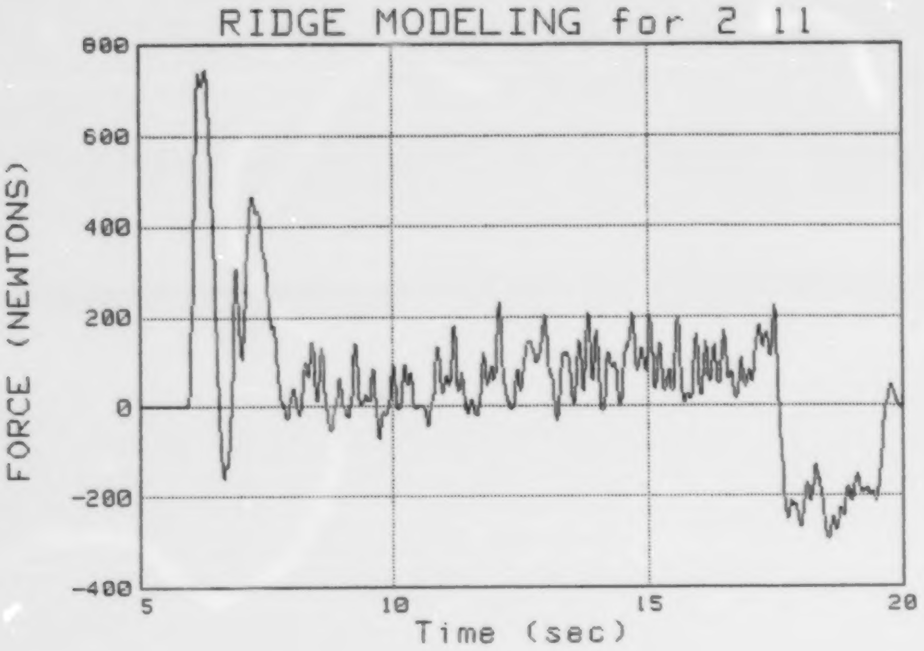

RIDGE MODELING for 2 10
POSITION (METERS)
8
6
4
2
0
15
20
25
30
35
Time (sec)

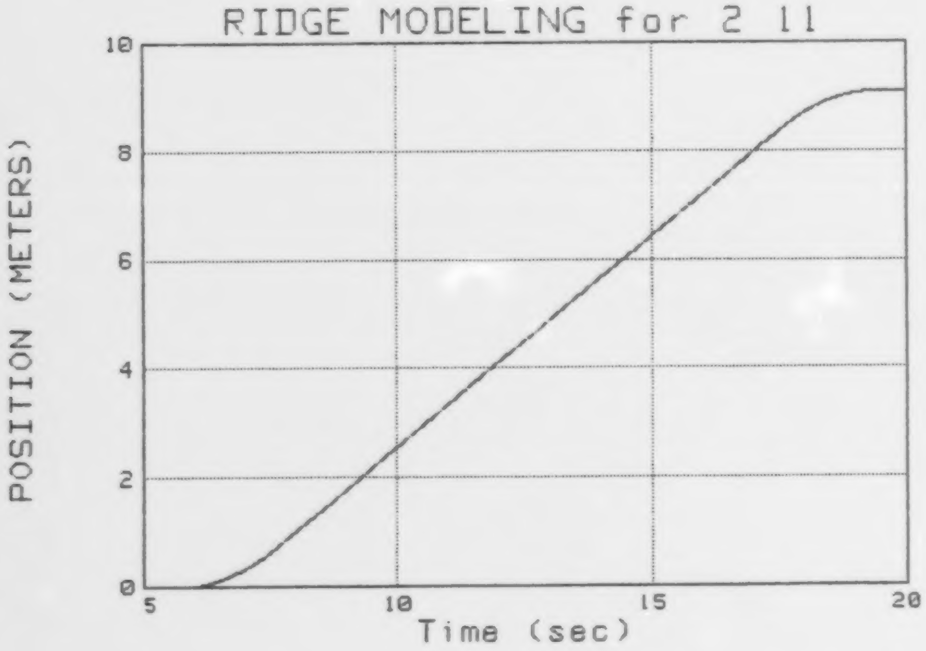

RIDGE MODELING
Project:3165C Test:2_10
+800.
+600.
+400.
+200.
+0.
-200.
-400.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
POSITION (METERS)

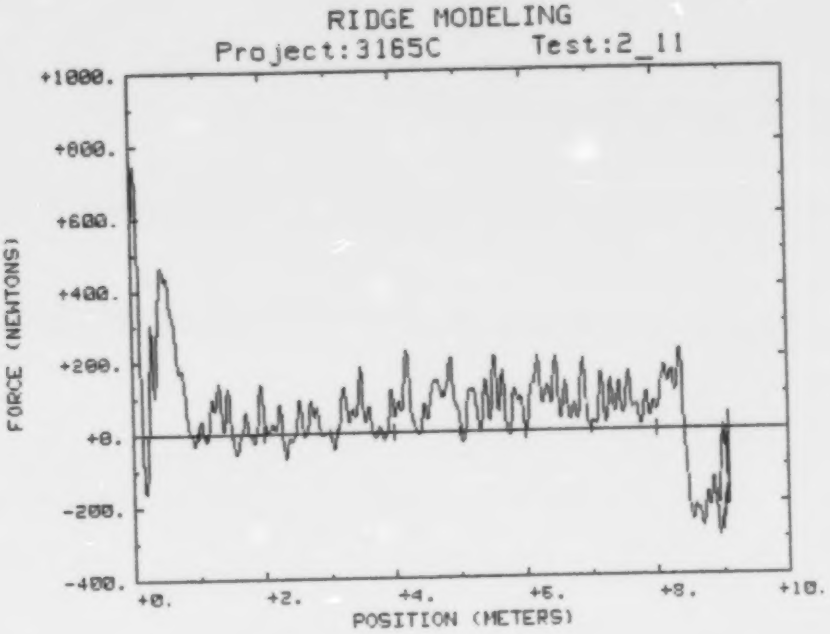

Ridge Modelling - Phase II
Test: 2_10 Date: 14 Aug 1989
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
-300.
-350.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
POSITION (METERS)

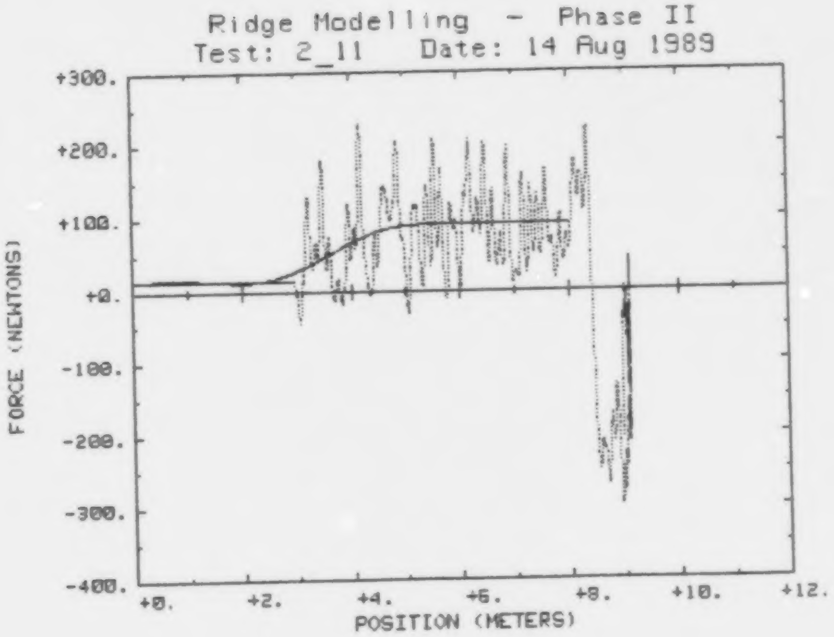

Ridge Modelling - Phase II
Test: 2_10 Date: 14 Aug 1989

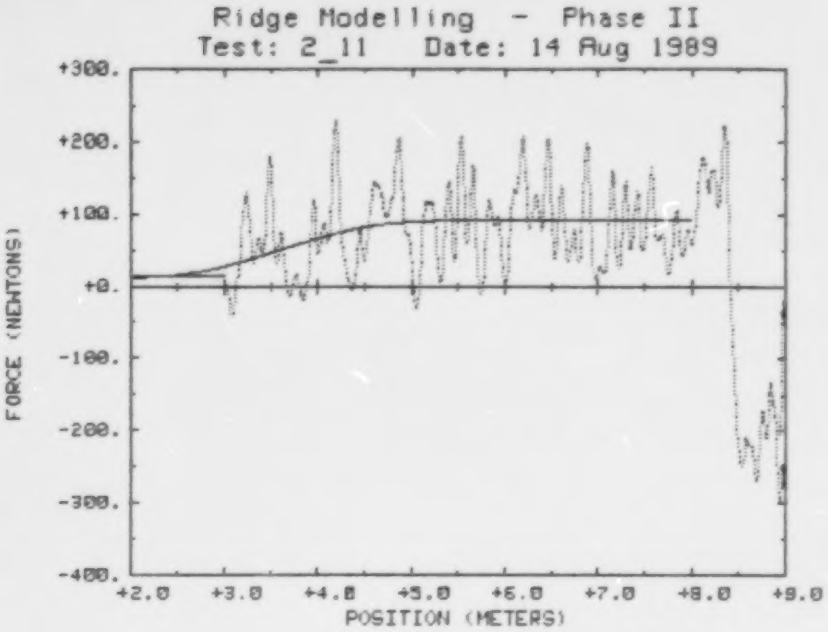

Ridge Modelling - Phase II
Test: 2_10 Date: 14 Aug 1989

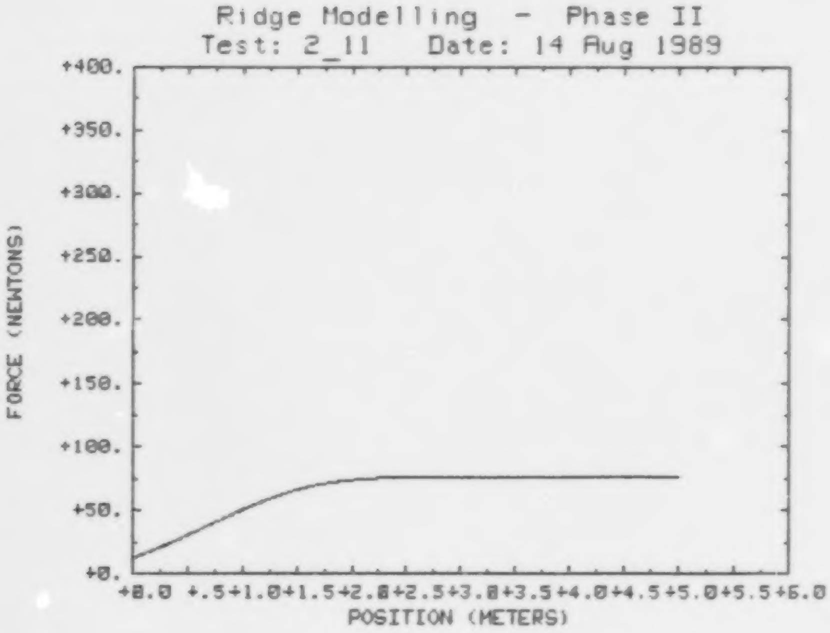

RIDGE MODELING for 2 11
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
5
10
15
20
Time (sec)

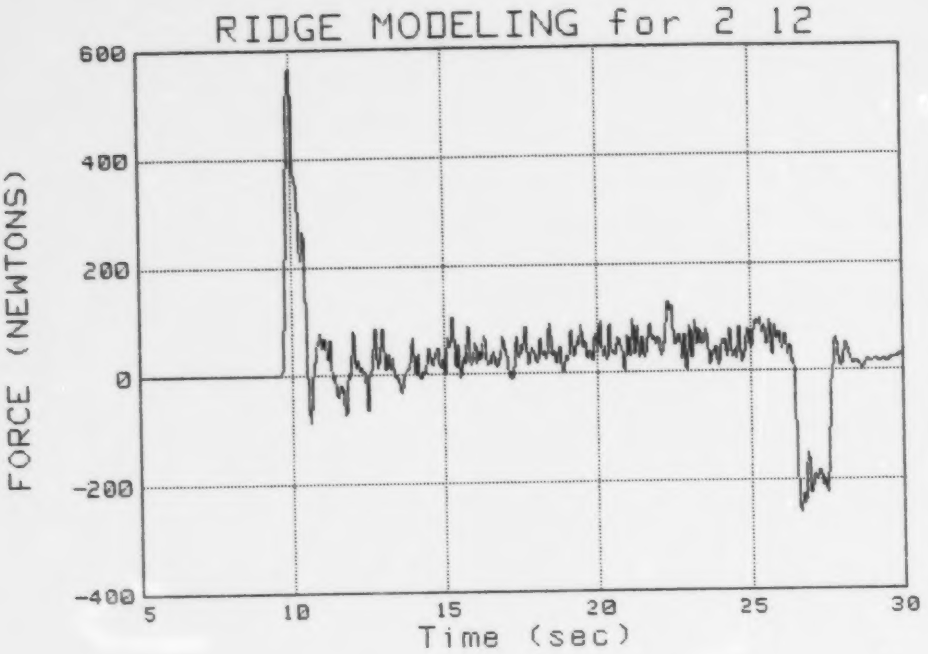

RIDGE MODELING for 2 11
POSITION (METERS)
10
8
6
4
2
0
5
10
15
20
Time (sec)


RIDGE MODELING
Project:3165C Test:2_11
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
FORCE (NEWTONS)
+0.
+2.
+4.
+6.
+8.
+10.
POSITION (METERS)

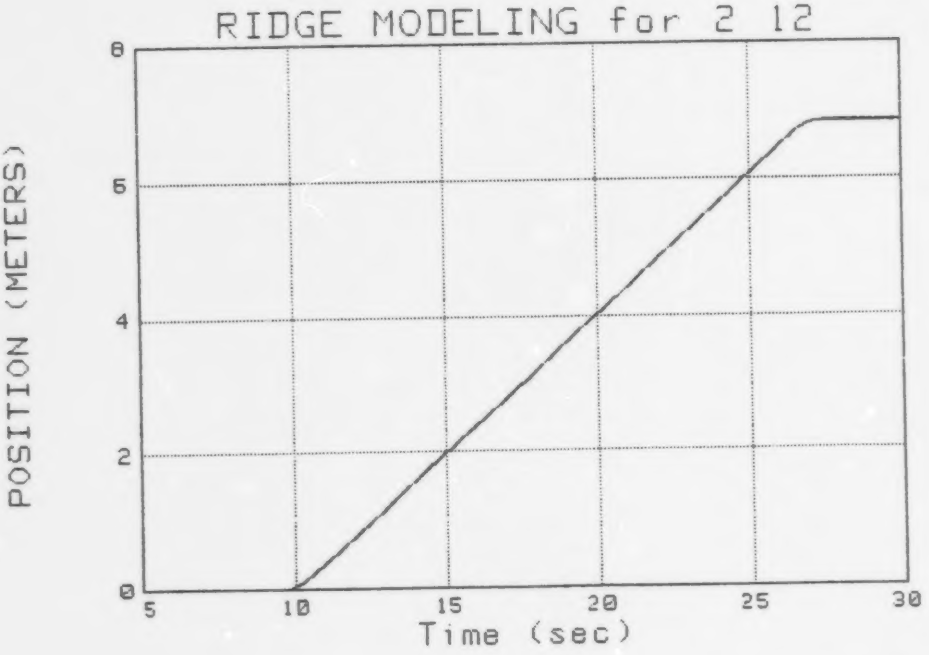

Ridge Modelling - Phase II
Test: 2_11 Date: 14 Aug 1989
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
FORCE (NEWTONS)
+0.
+2.
+4.
+6.
+8.
+10.
+12.
POSITION (METERS)


Ridge Modelling - Phase II
Test: 2_11 Date: 14 Aug 1989

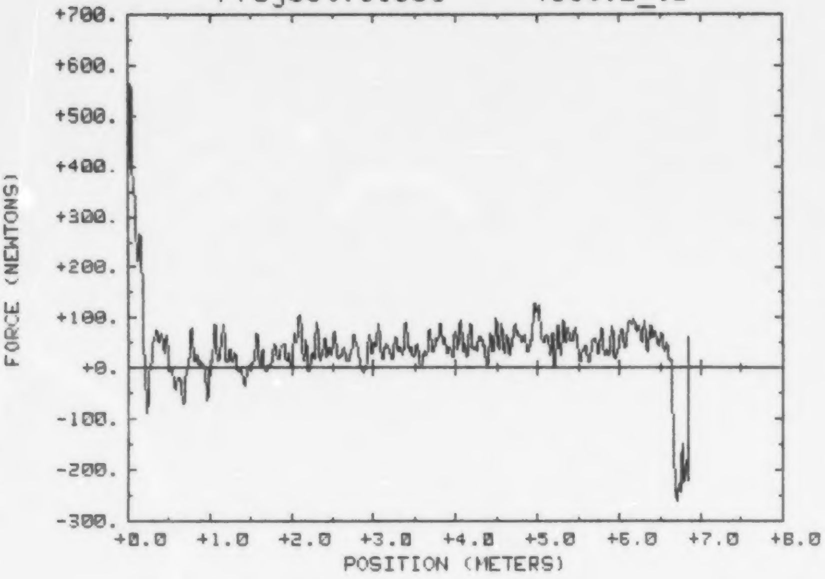

Ridge Modelling - Phase II
Test: 2_11 Date: 14 Aug 1989

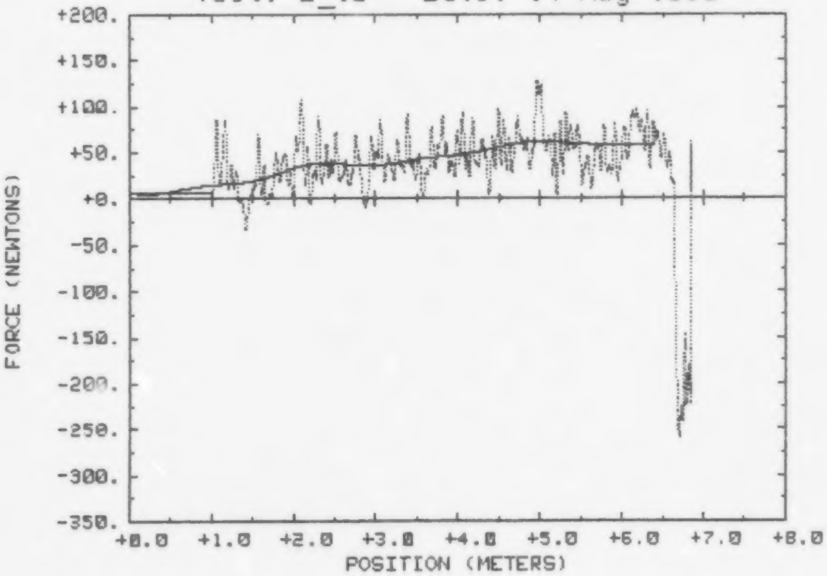


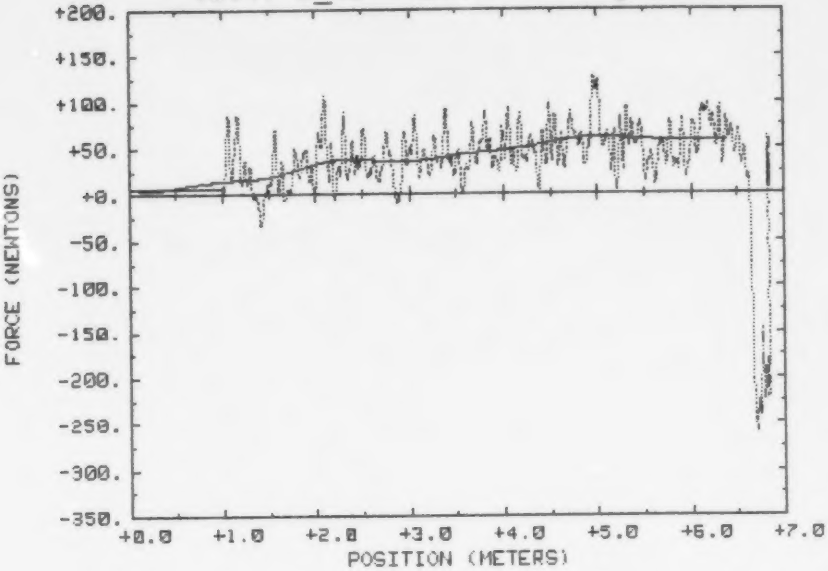
RIDGE MODELING for 2 12



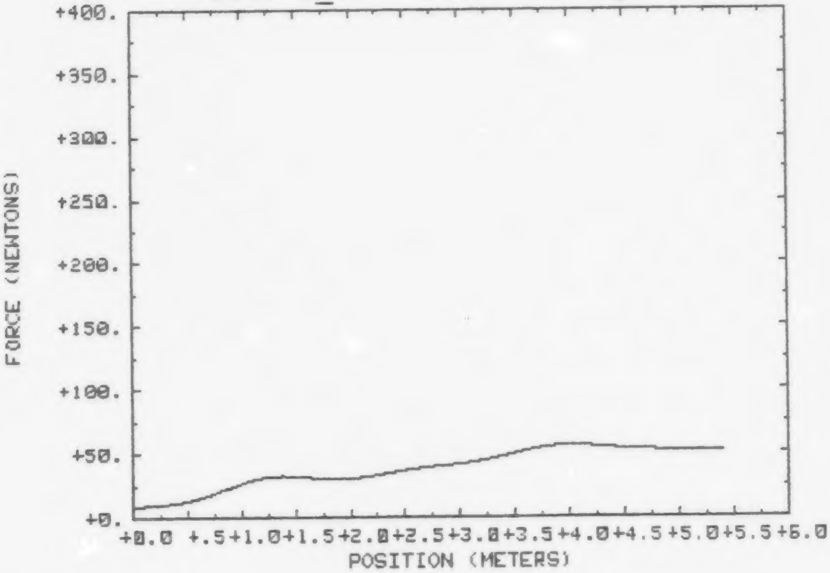
RIDGE MODELING for 2 12


RIDGE MODELING
Project:3165C Test:2_12

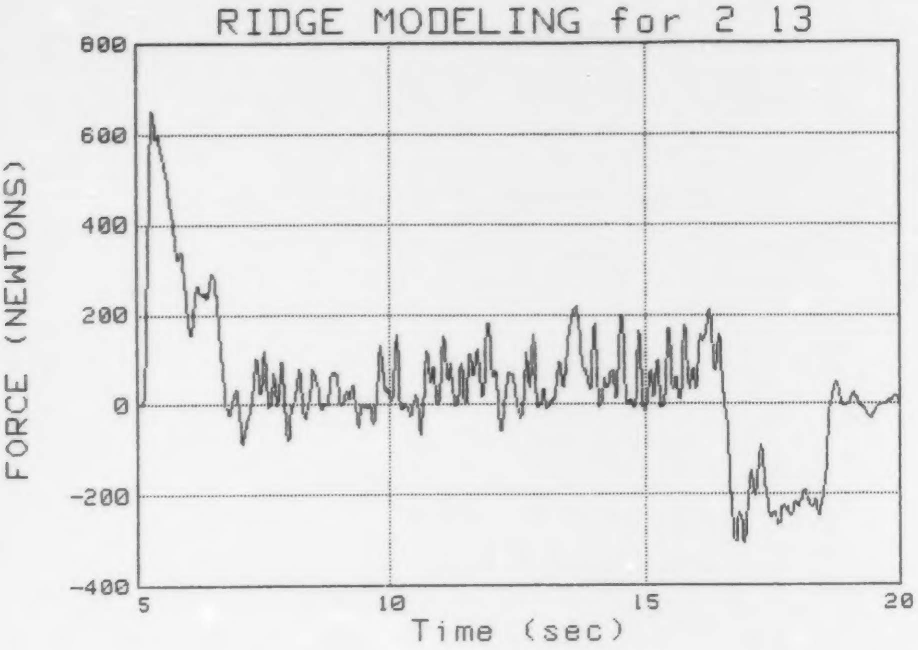

Ridge Modelling - Phase II
Test: 2_12 Date: 14 Aug 1989

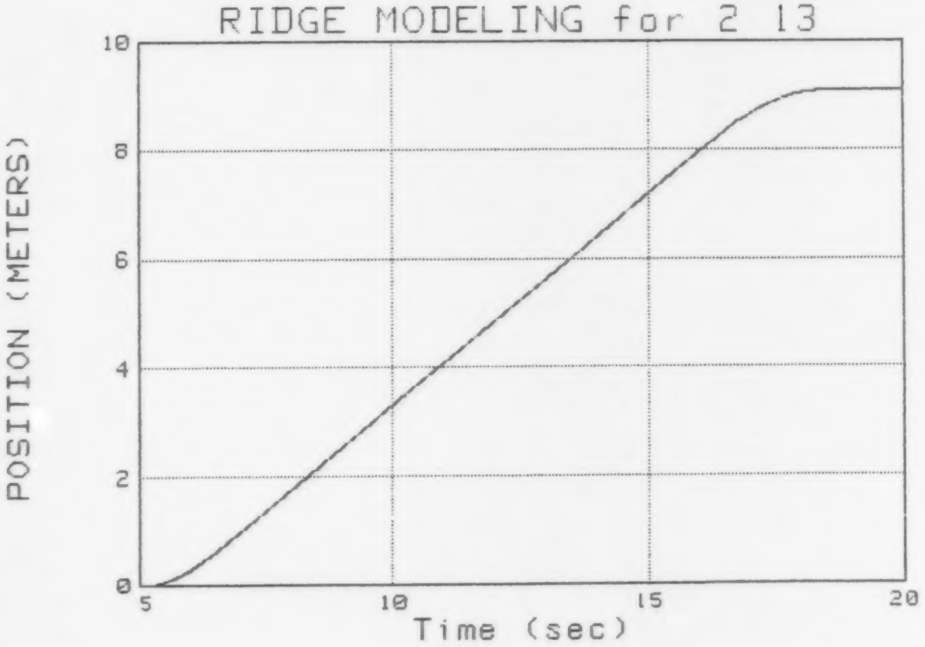


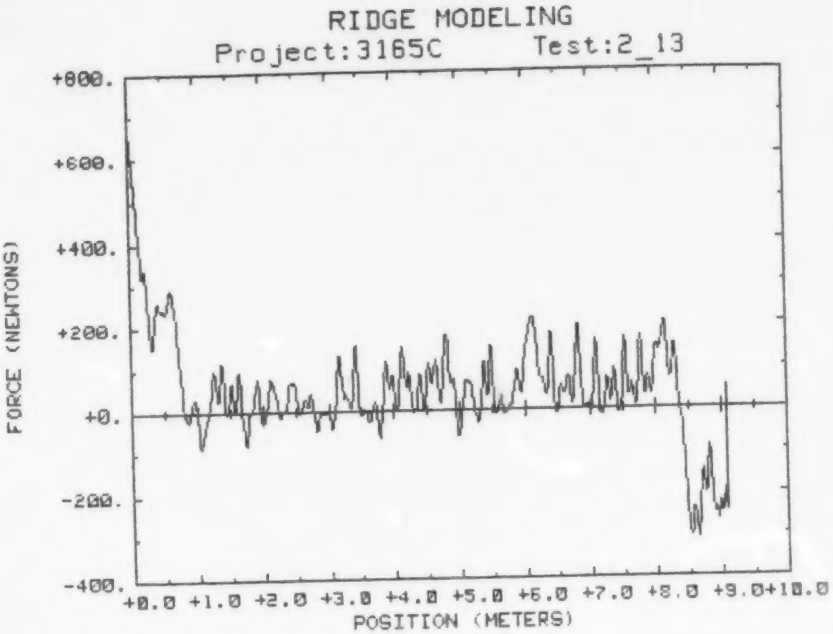
Ridge Modelling - Phase II
Test: 2_12 Date: 14 Aug 1989

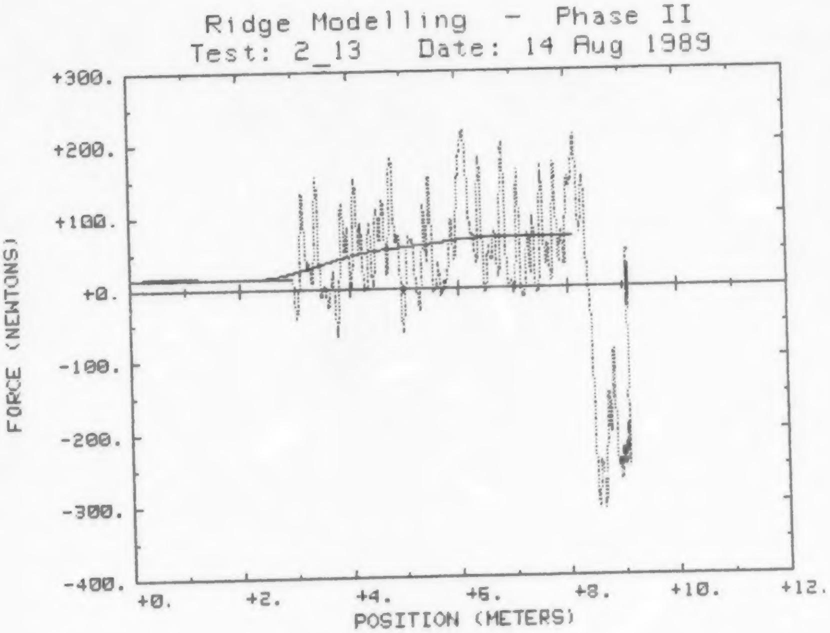


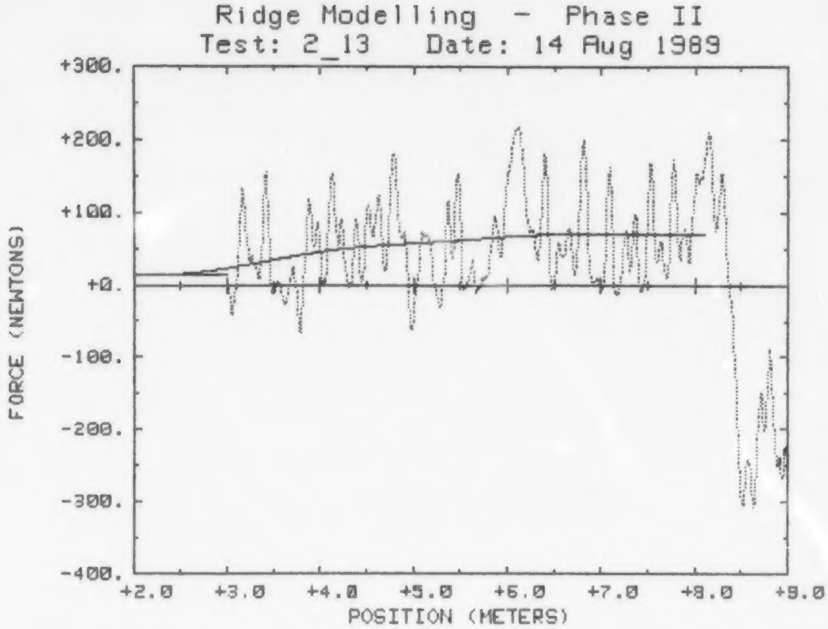
Ridge Modelling - Phase II
Test: 2_12 Date: 14 Aug 1989

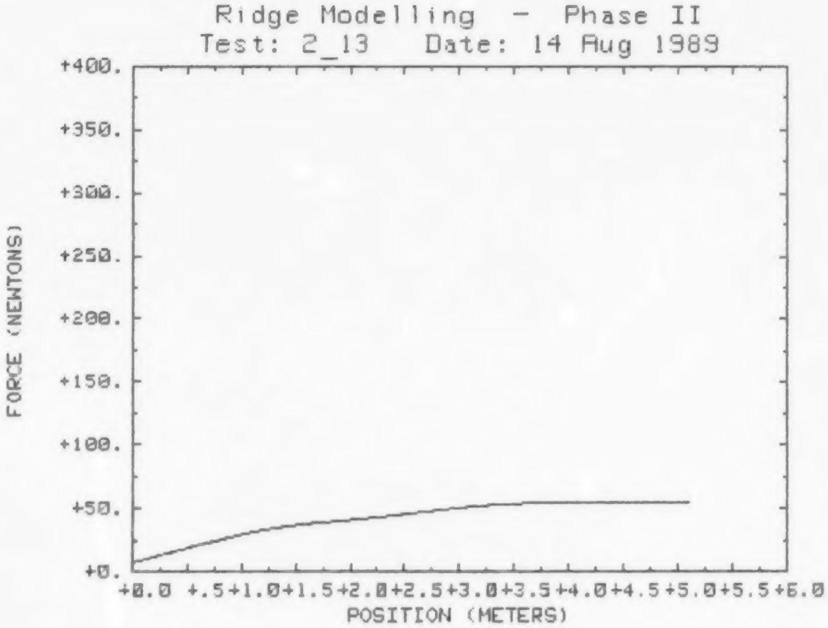

RIDGE MODELING for 2 13
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
5
10
15
20
Time (sec)


RIDGE MODELING for 2 13
POSITION (METERS)
10
8
6
4
2
0
5
10
15
20
Time (sec)


RIDGE MODELING
Project:3165C Test:2_13
FORCE (NEWTONS)
+800.
+600.
+400.
+200.
+0.
-200.
-400.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

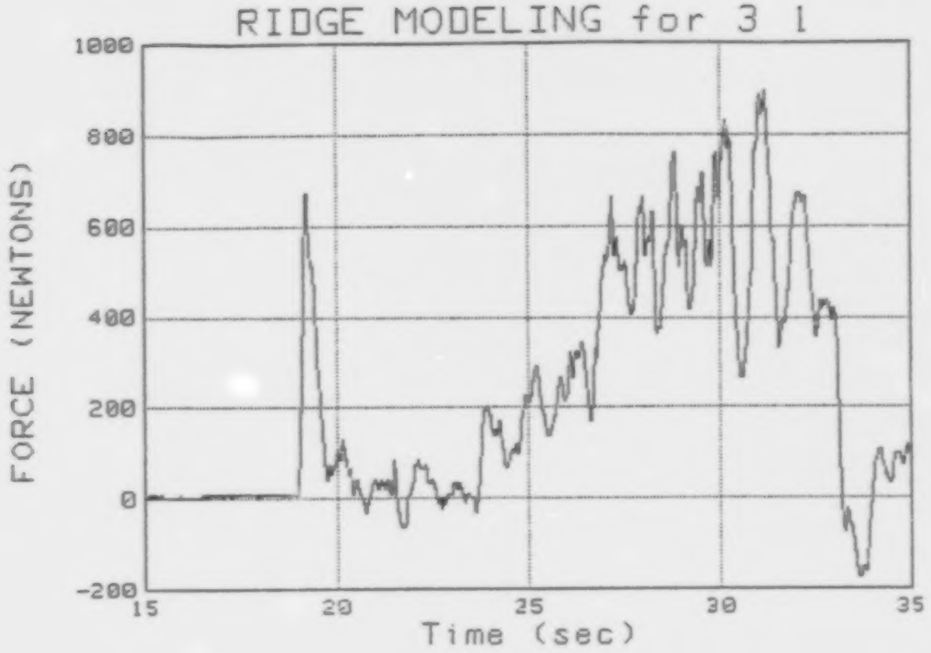

Ridge Modelling - Phase II
Test: 2_13 Date: 14 Aug 1989
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
+0. +2. +4. +6. +8. +10. +12.
POSITION (METERS)

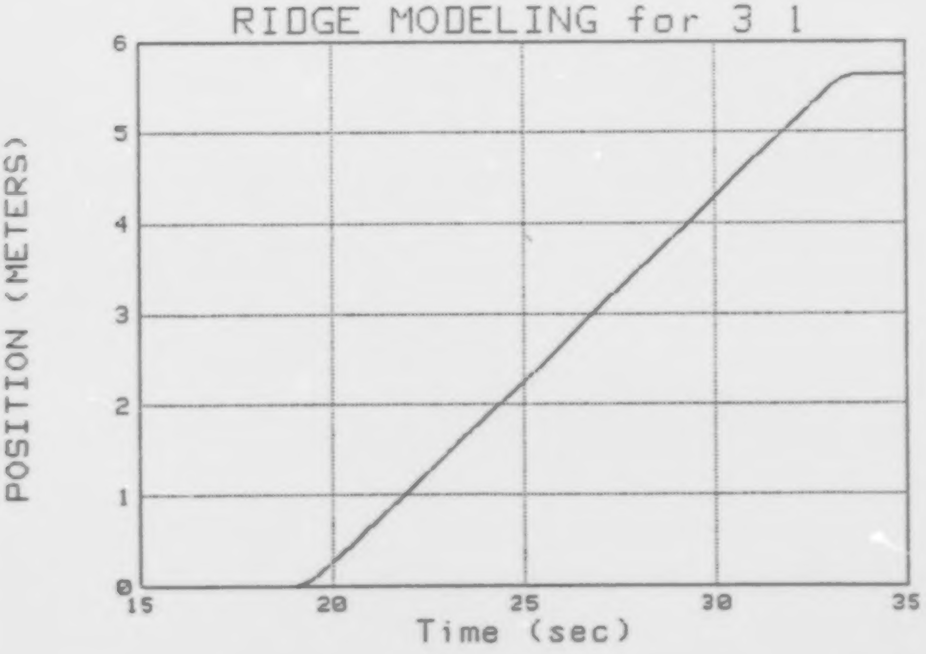

Ridge Modelling - Phase II
Test: 2_13 Date: 14 Aug 1989

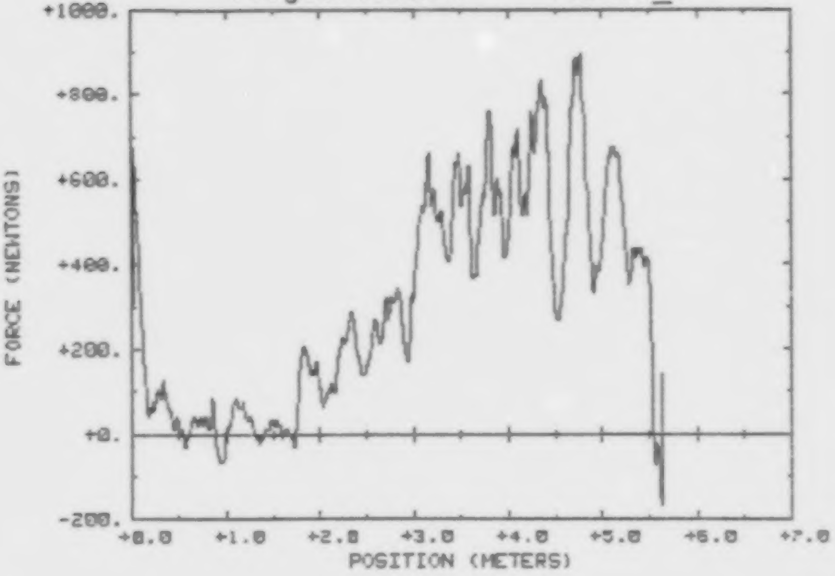

Ridge Modelling - Phase II
Test: 2_13 Date: 14 Aug 1989

APPENDIX C

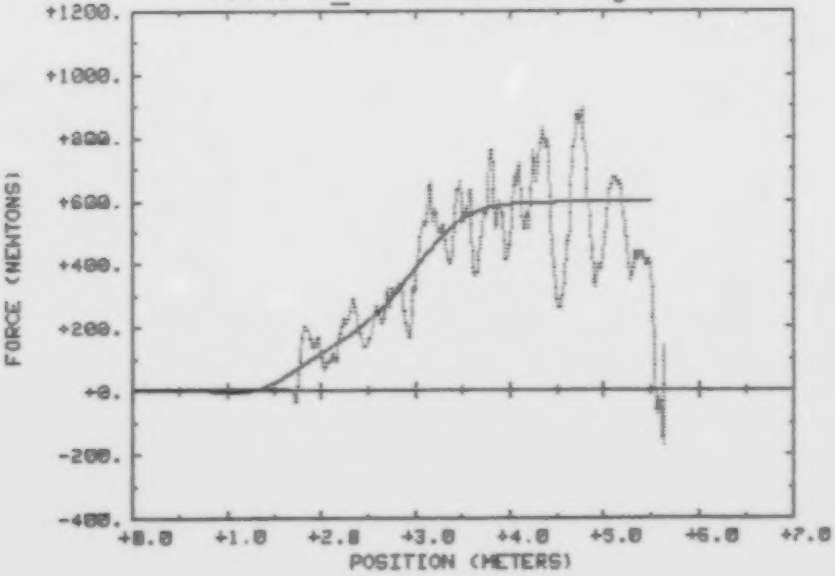
TEST DATA FOR SHEET #3


RIDGE MODELING for 3 1
FORCE (NEWTONS)
1000
800
600
400
200
0
-200
15
20
25
30
35
Time (sec)

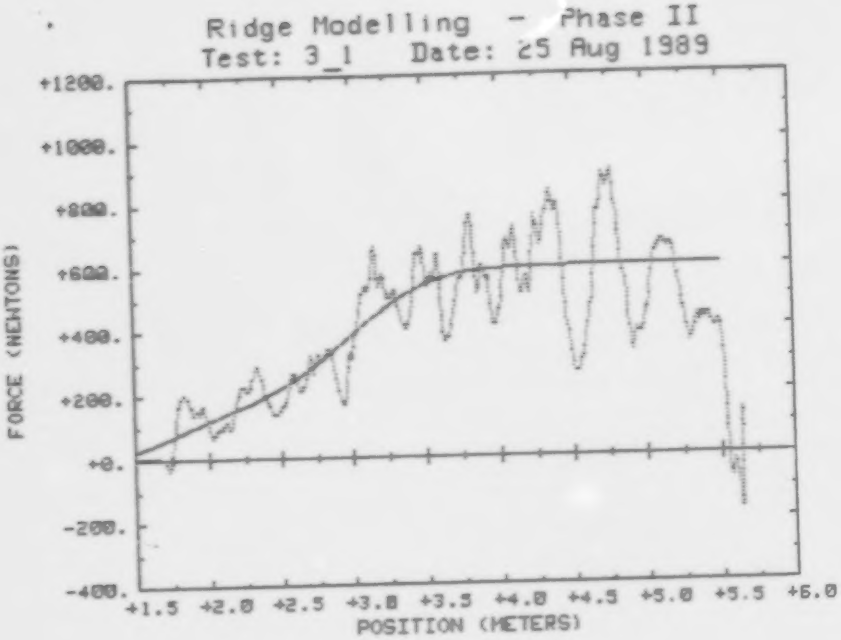

RIDGE MODELING for 3 1
POSITION (METERS)
6
5
4
3
2
1
0
15
20
25
30
35
Time (sec)

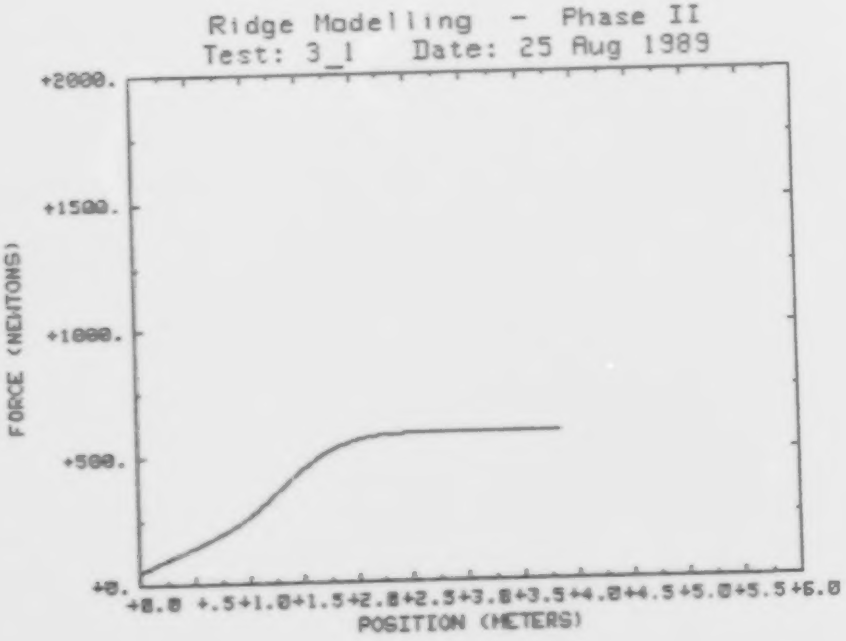


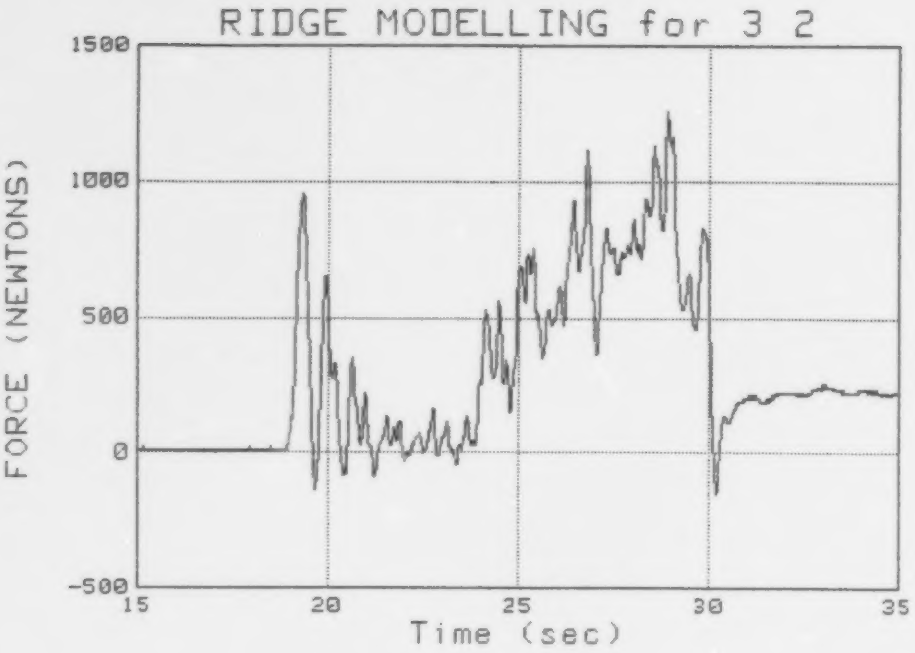
RIDGE MODELING
Project:3165C Test:3_1

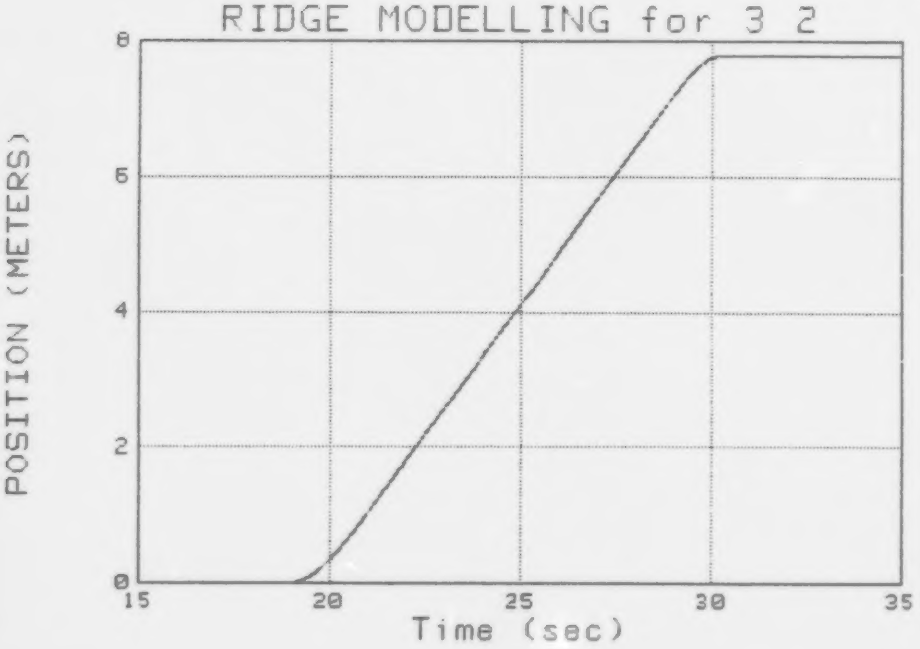


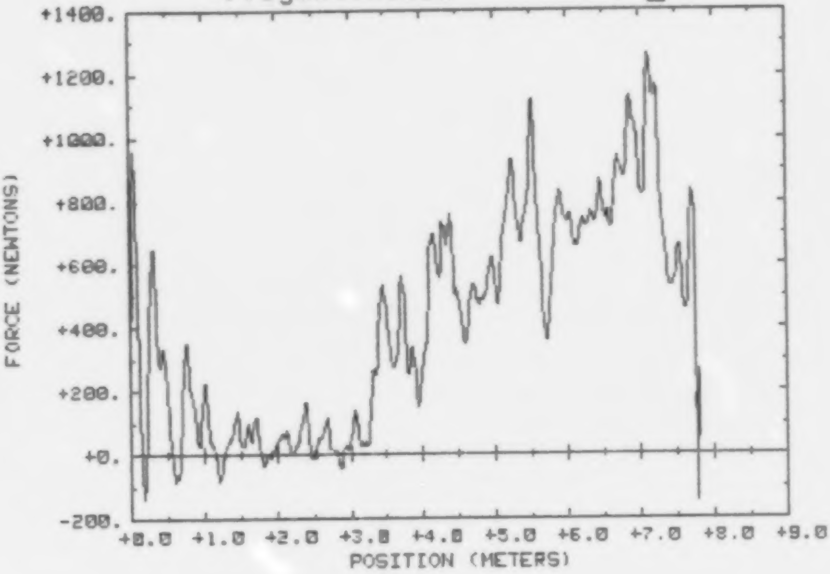
Ridge Modelling - Phase II
Test: 3_1 Date: 25 Aug 1989


Ridge Modelling - Phase II
Test: 3_1 Date: 25 Aug 1989
FORCE (NEWTONS)
+1200.
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

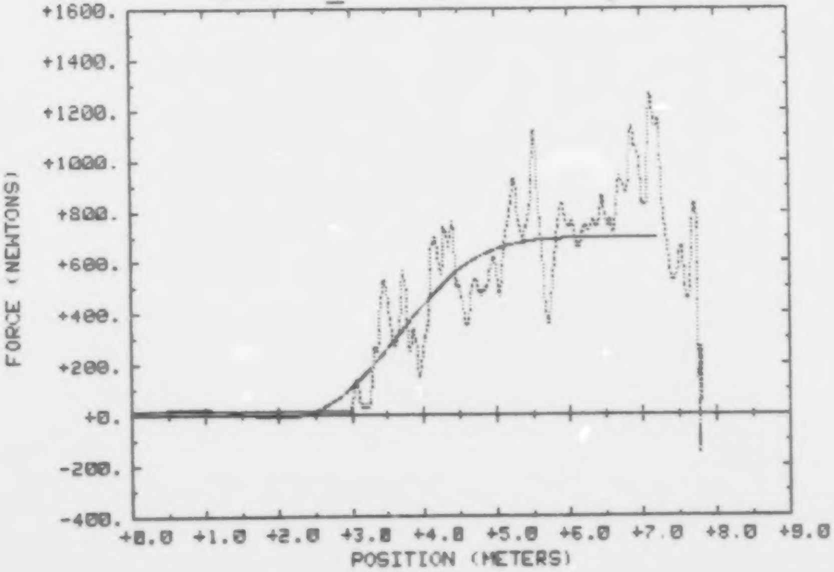

Ridge Modelling - Phase II
Test: 3_1 Date: 25 Aug 1989
FORCE (NEWTONS)
+2000.
+1500.
+1000.
+500.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)


RIDGE MODELLING for 3 2
FORCE (NEWTONS)
1500
1000
500
0
-500
15
20
25
30
35
Time (sec)

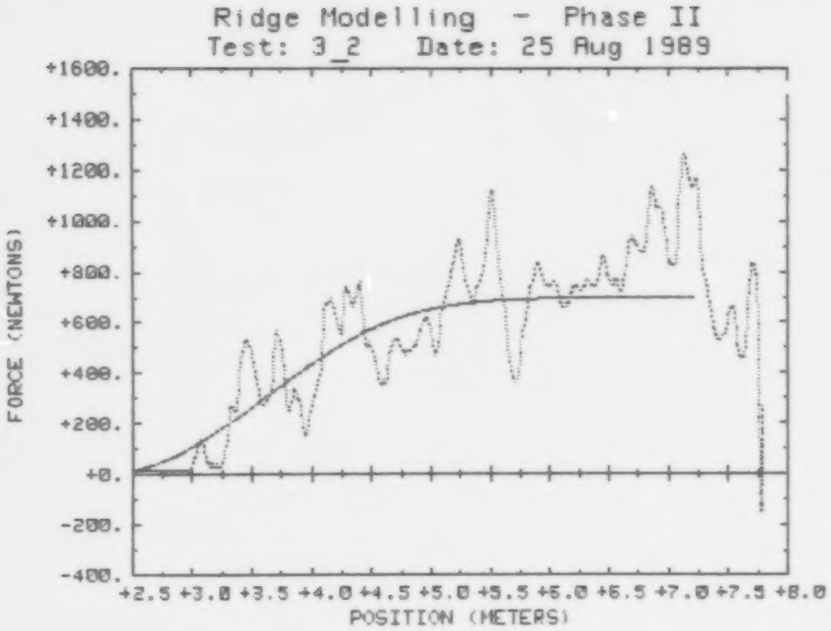

RIDGE MODELLING for 3 2
POSITION (METERS)
8
6
4
2
0
15
20
25
30
35
Time (sec)

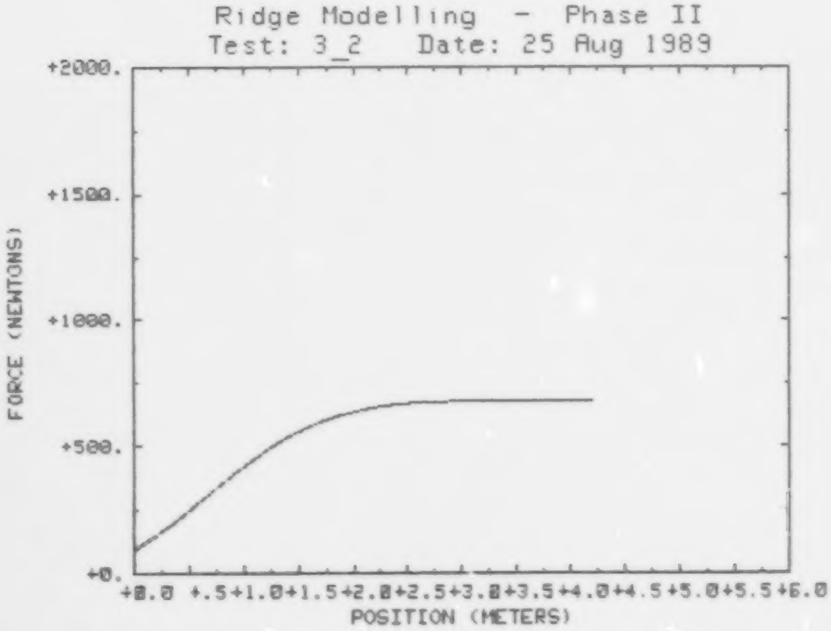


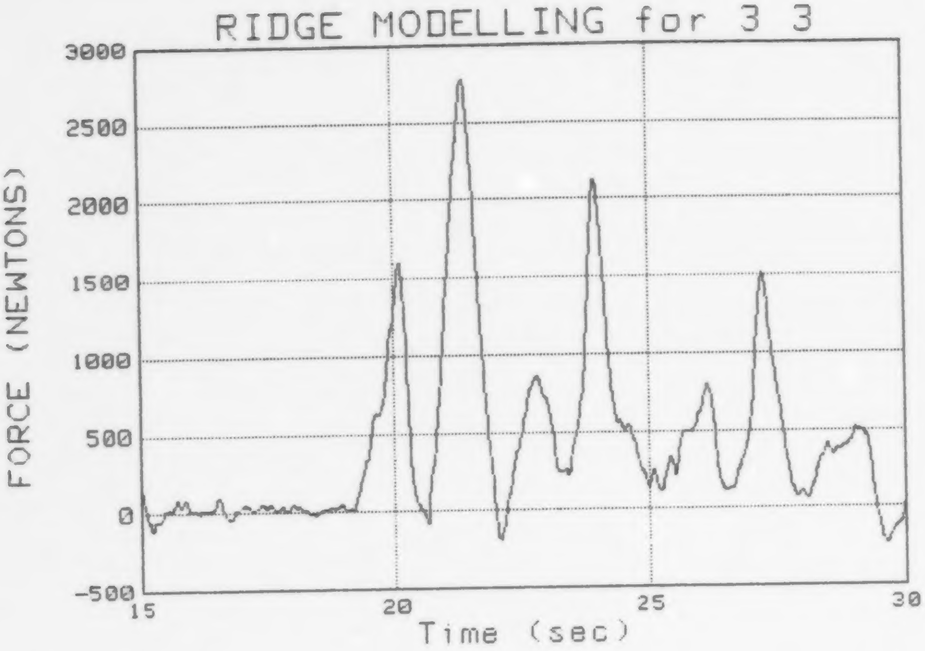
RIDGE MODELLING
Project:3165C Test:3_2

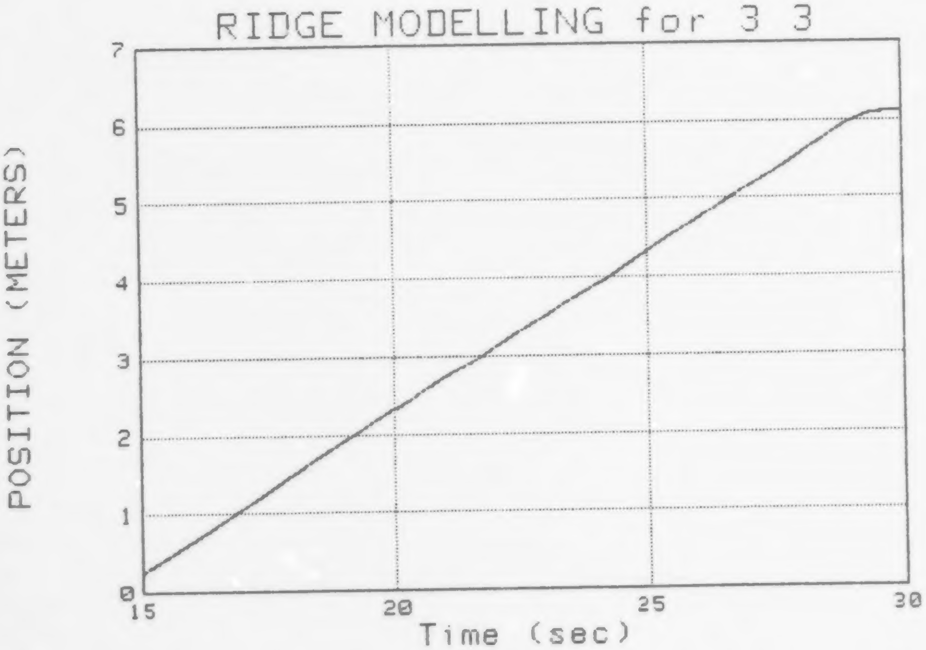


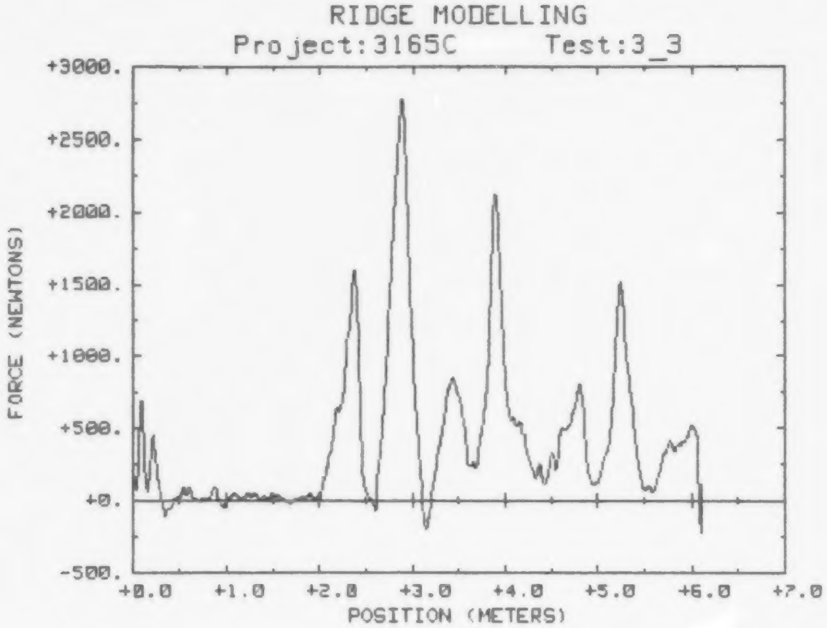
Ridge Modelling - Phase II
Test: 3_2 Date: 25 Aug 1989

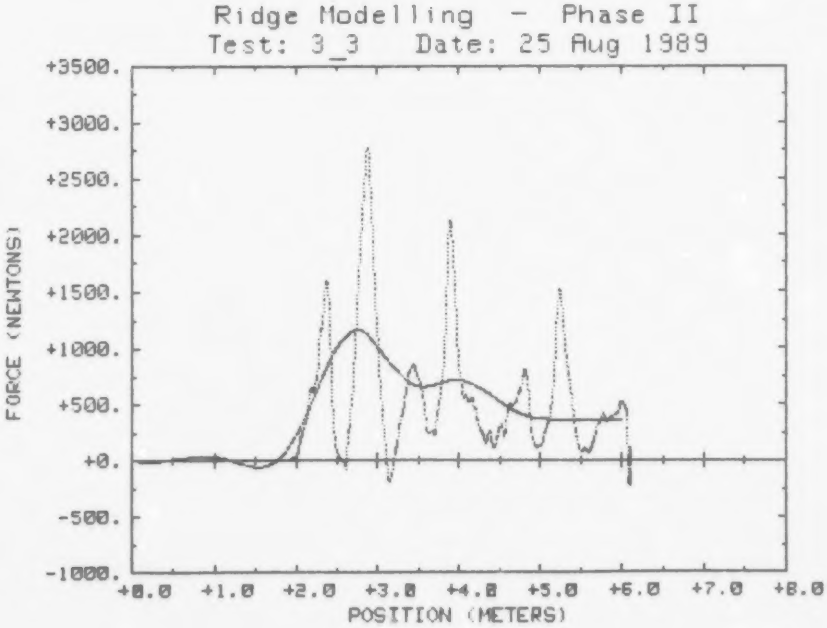

Ridge Modelling - Phase II
Test: 3_2 Date: 25 Aug 1989
FORCE (NEWTONS)
+1600.
+1400.
+1200.
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
+2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0 +6.5 +7.0 +7.5 +8.0
POSITION (METERS)

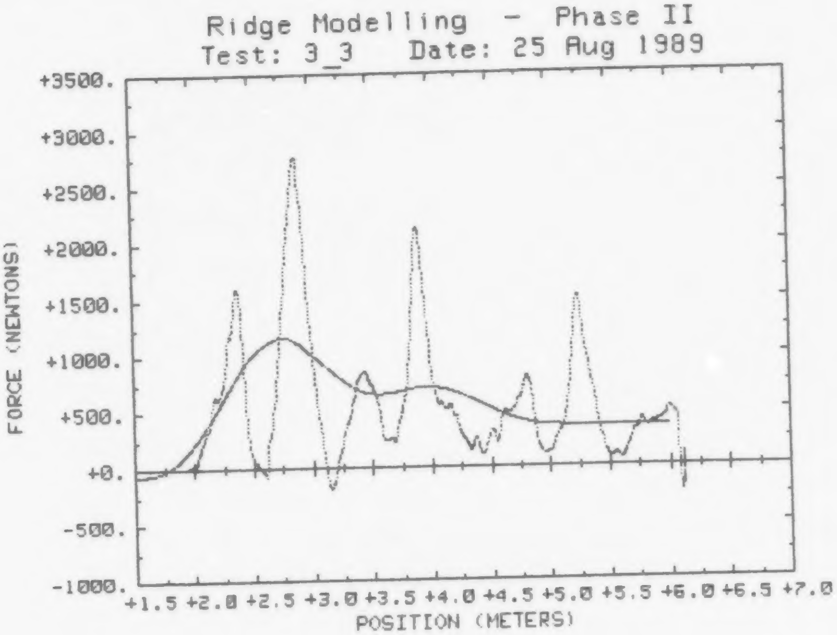

Ridge Modelling - Phase II
Test: 3_2 Date: 25 Aug 1989
FORCE (NEWTONS)
+2000.
+1500.
+1000.
+500.
+0.
+0.0 +.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0
POSITION (METERS)

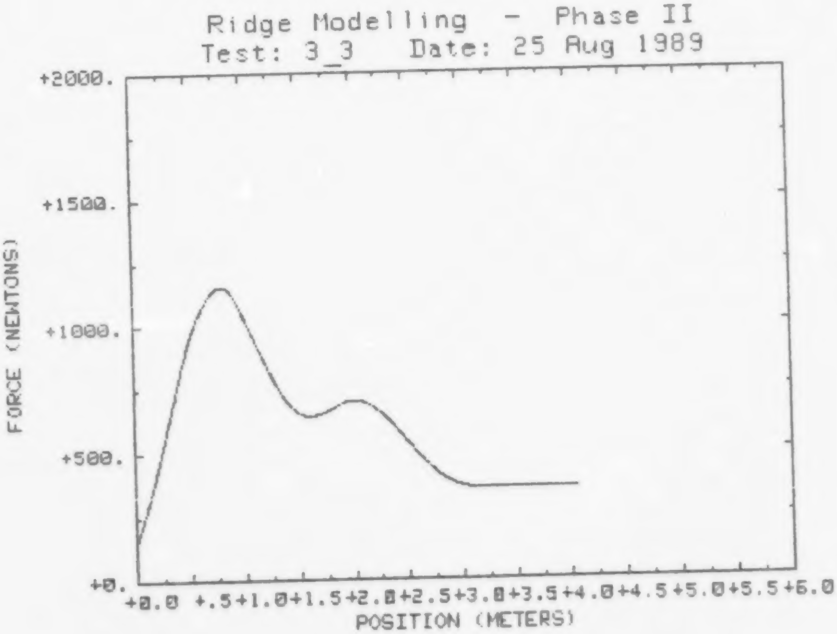

RIDGE MODELLING for 3 3
FORCE (NEWTONS)
3000
2500
2000
1500
1000
500
0
-500
15
20
25
30
Time (sec)

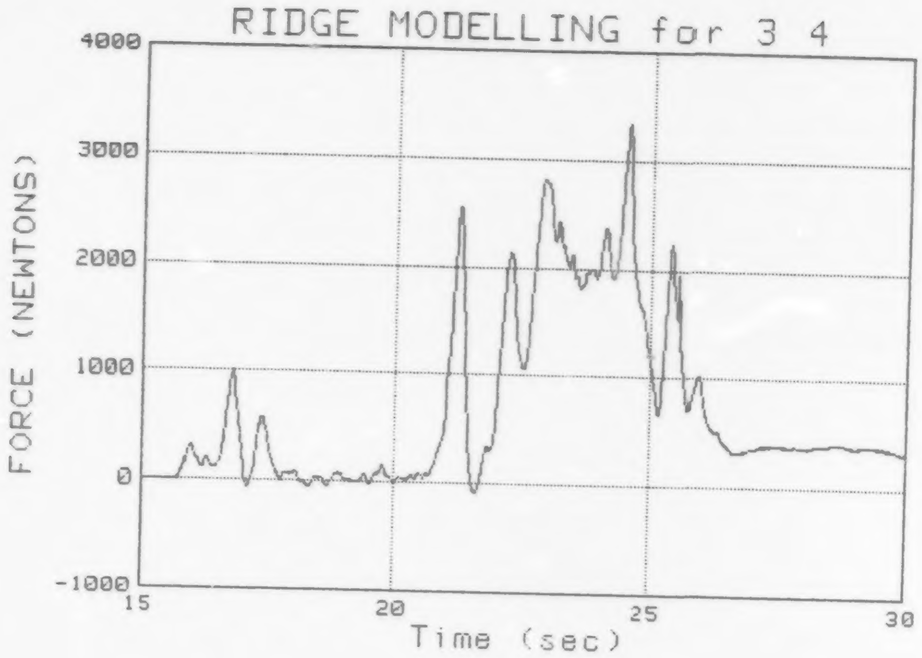

RIDGE MODELLING for 3 3
POSITION (METERS)
7
6
5
4
3
2
1
0
15
20
25
30
Time (sec)

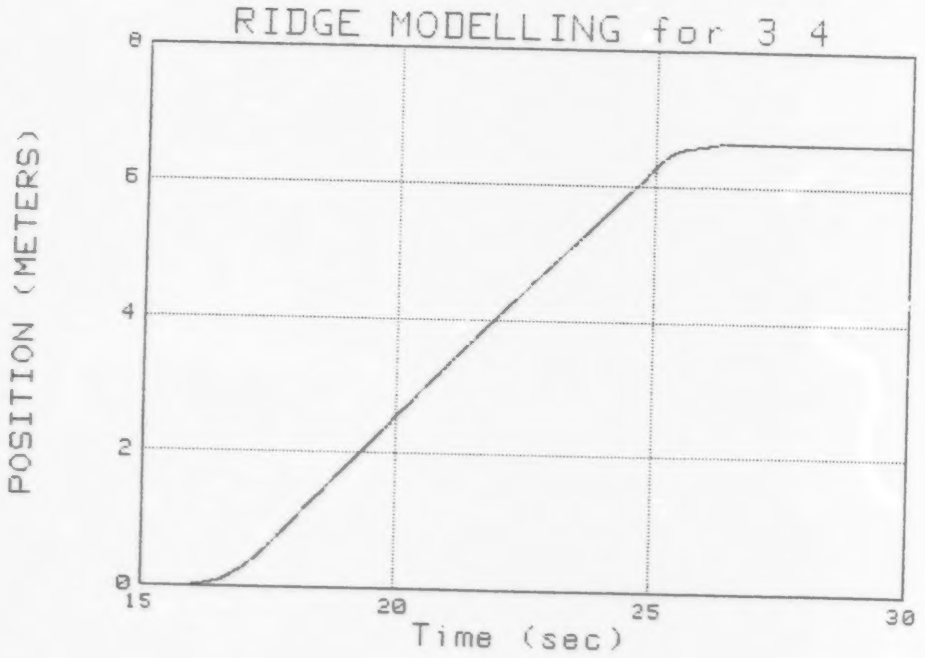

RIDGE MODELLING
Project:3165C Test:3_3

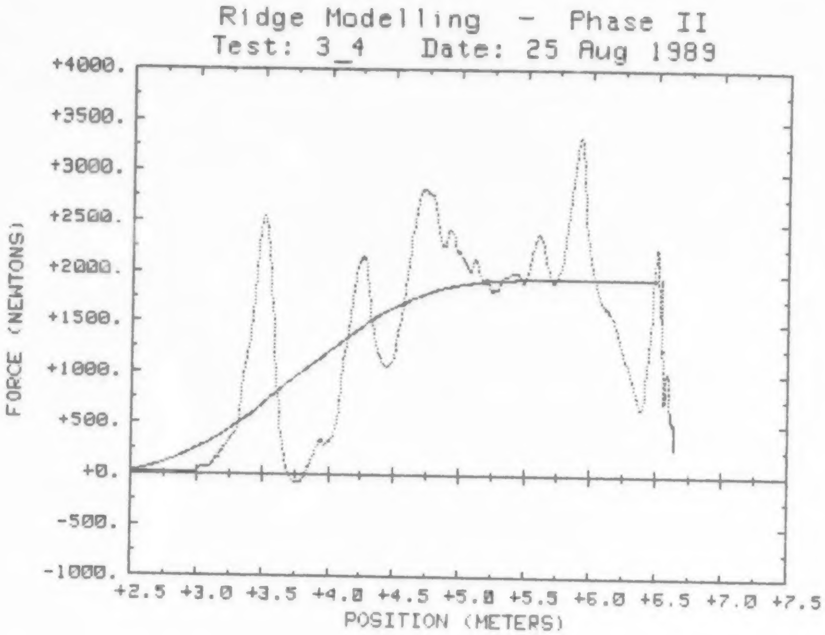

Ridge Modelling - Phase II
Test: 3_3 Date: 25 Aug 1989

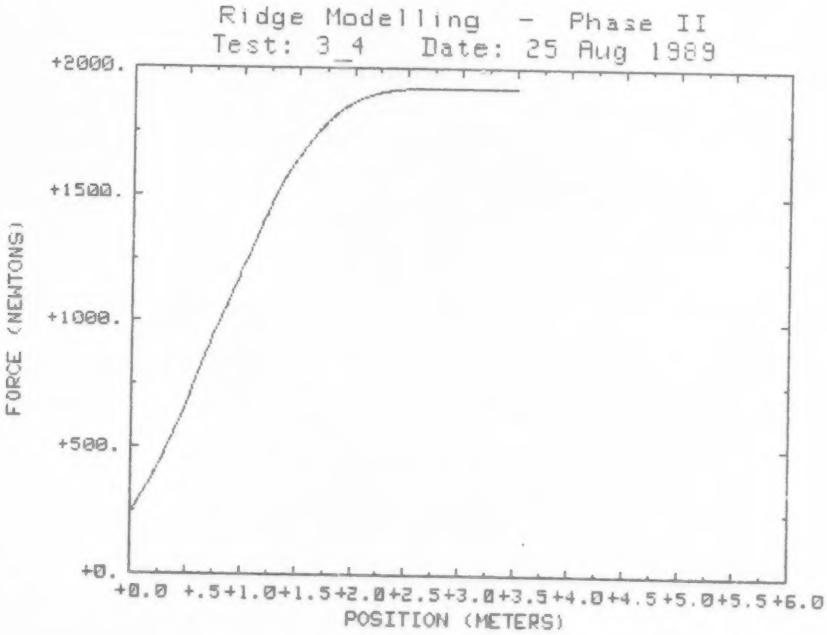

Ridge Modelling - Phase II
Test: 3_3 Date: 25 Aug 1989
+3500.
+3000.
+2500.
+2000.
+1500.
+1000.
+500.
+0.
-500.
-1000.
FORCE (NEWTONS)
+1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0 +6.5 +7.0
POSITION (METERS)

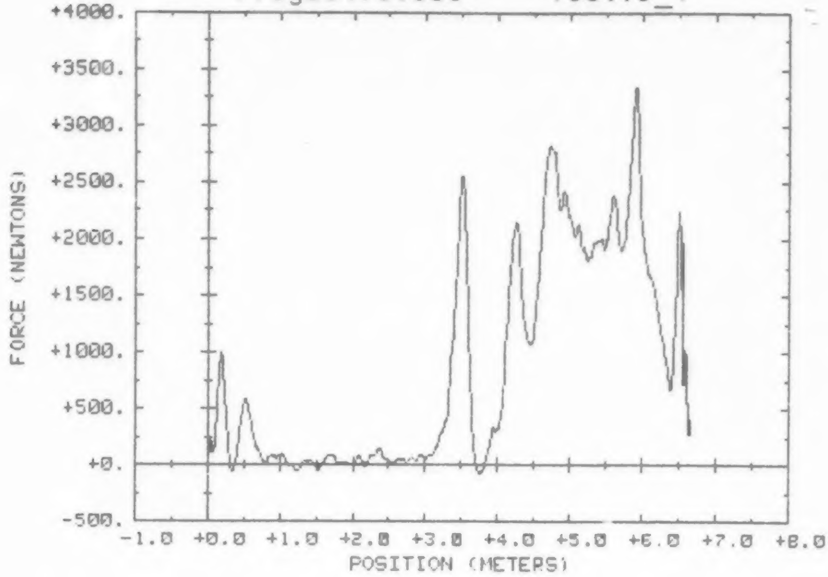

Ridge Modelling - Phase II
Test: 3_3 Date: 25 Aug 1989
+2000.
+1500.
+1000.
+500.
+0.
FORCE (NEWTONS)
+0.0 +.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0
POSITION (METERS)


RIDGE MODELLING for 3 4
FORCE (NEWTONS)
4000
3000
2000
1000
0
-1000
15
20
25
30
Time (sec)

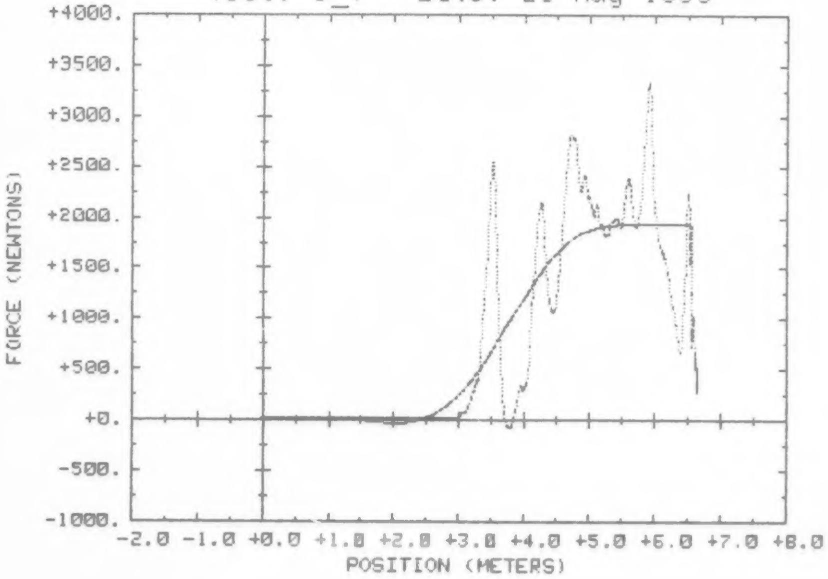

RIDGE MODELLING for 3 4
POSITION (METERS)
8
6
4
2
0
15
20
25
30
Time (sec)


Ridge Modelling - Phase II
Test: 3_4 Date: 25 Aug 1989
+4000.
+3500.
+3000.
+2500.
+2000.
+1500.
+1000.
+500.
+0.
-500.
-1000.
FORCE (NEWTONS)
+2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0 +6.5 +7.0 +7.5
POSITION (METERS)


Ridge Modelling - Phase II
Test: 3_4 Date: 25 Aug 1989
+2000.
+1500.
+1000.
+500.
+0.
FORCE (NEWTONS)
+0.0 +.5 +1.0 +1.5 +2.0 +2.5 +3.0 +3.5 +4.0 +4.5 +5.0 +5.5 +6.0
POSITION (METERS)

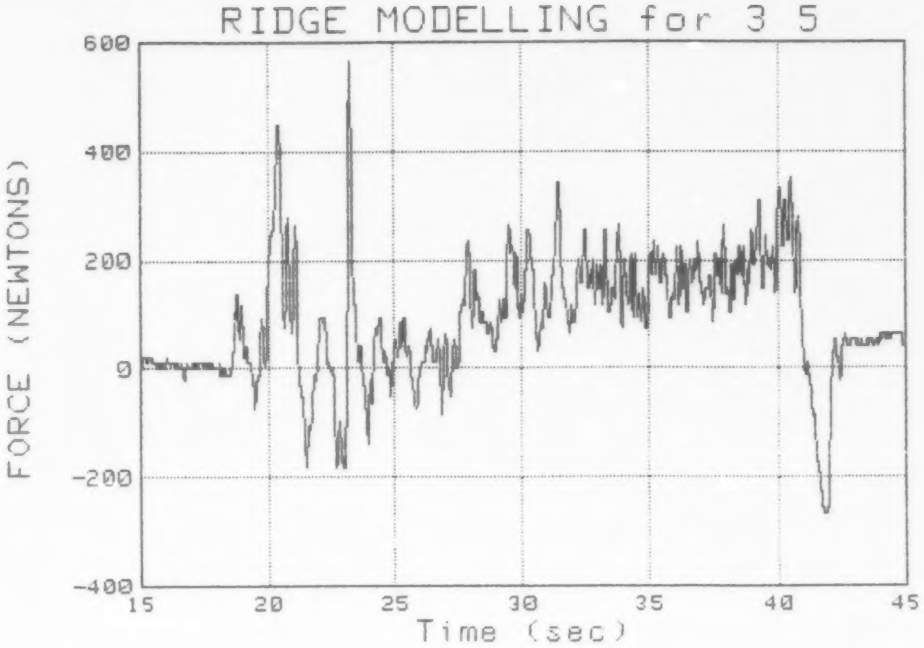


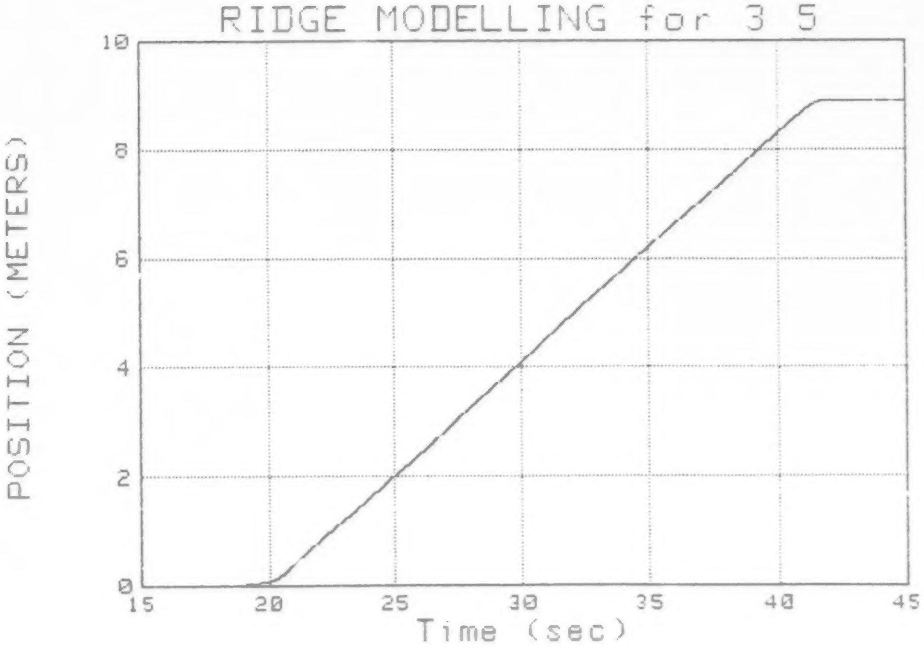
RIDGE MODELLING
Project:3165C Test:3_4

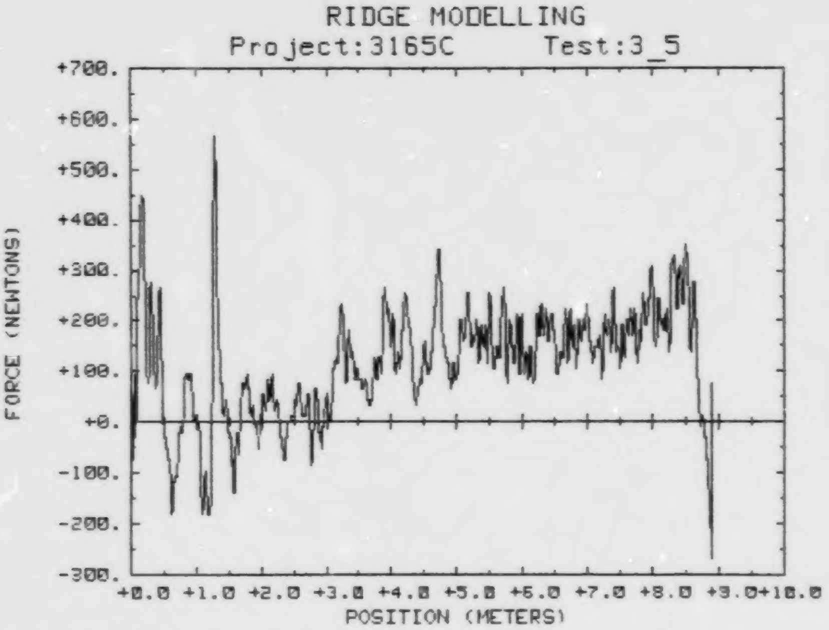


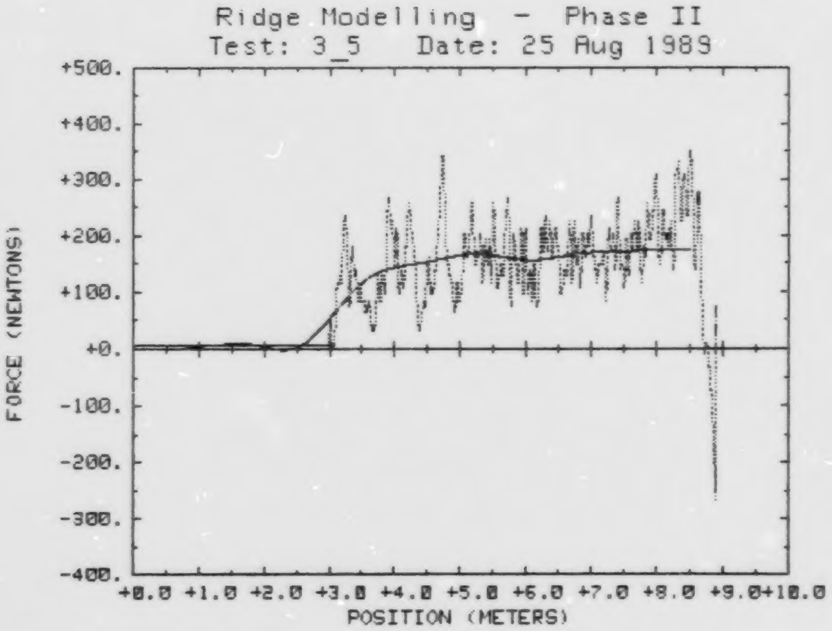
Ridge Modelling - Phase II
Test: 3_4 Date: 25 Aug 1989

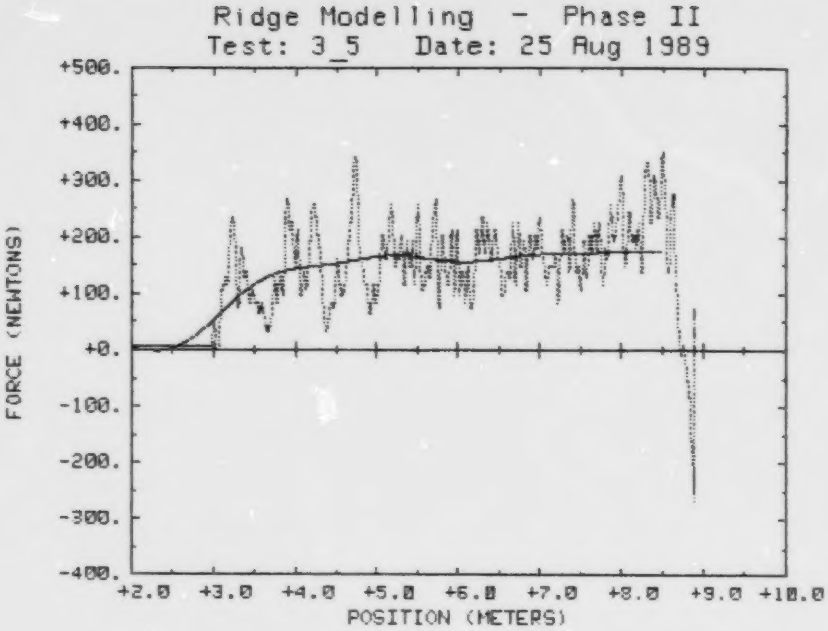
X


RIDGE MODELLING for 3 5

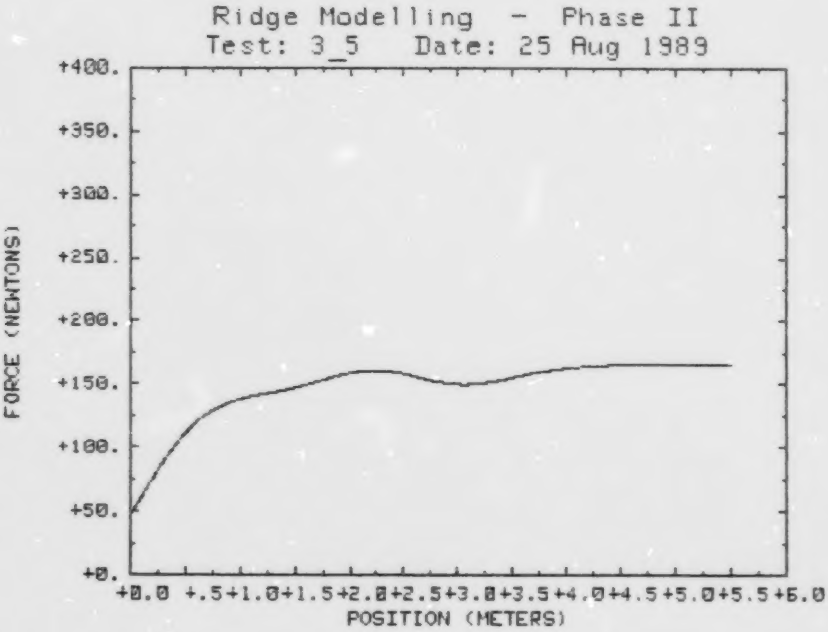

RIDGE MODELLING for 3 5


RIDGE MODELLING
Project:3165C Test:3_5

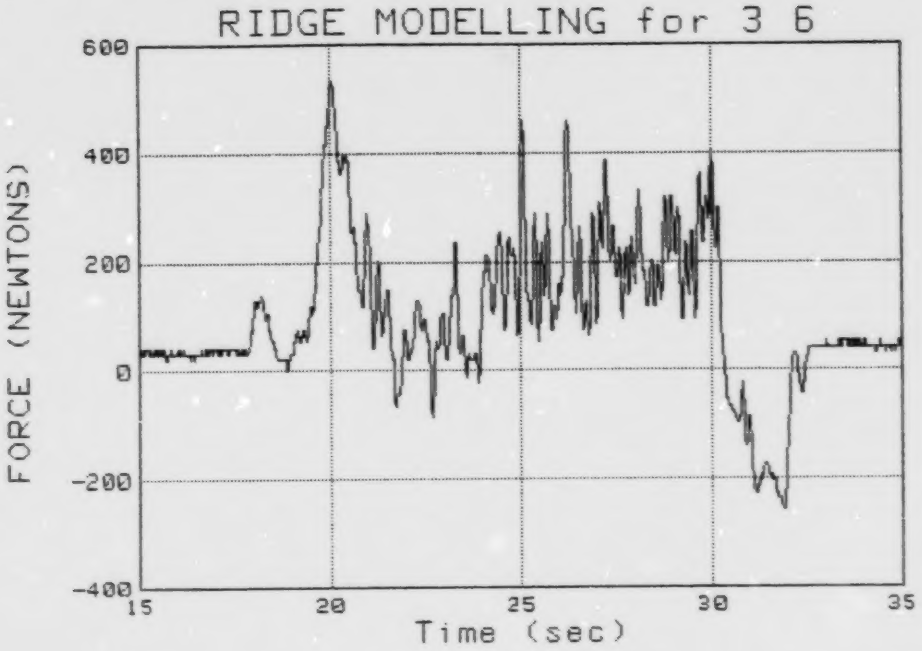

Ridge Modelling - Phase II
Test: 3_5 Date: 25 Aug 1989



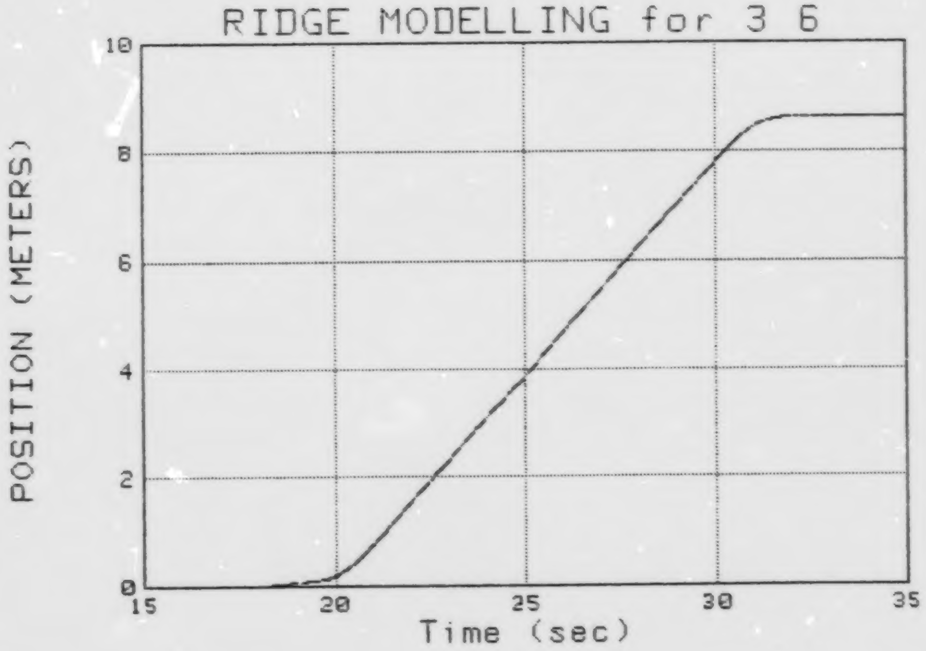
Ridge Modelling - Phase II
Test: 3_5 Date: 25 Aug 1989



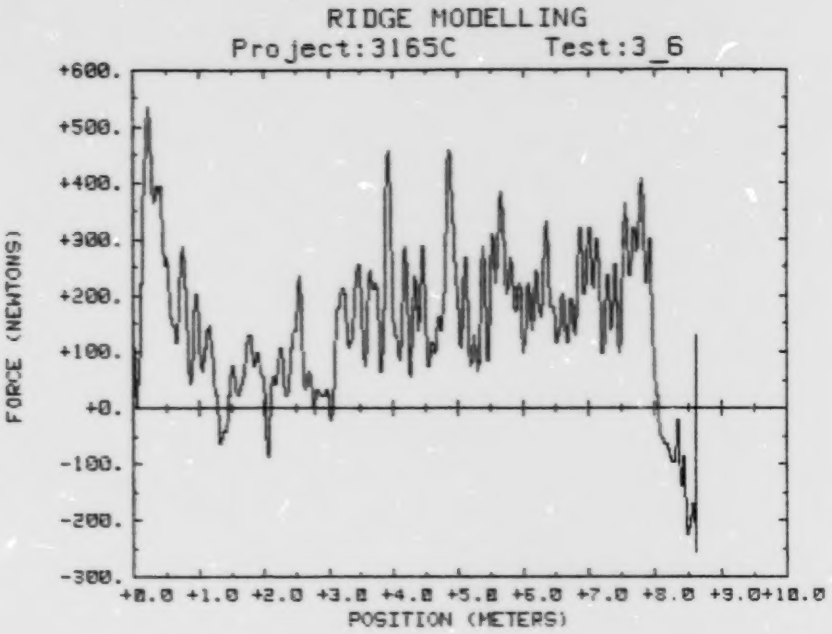
Ridge Modelling - Phase II
Test: 3_5 Date: 25 Aug 1989

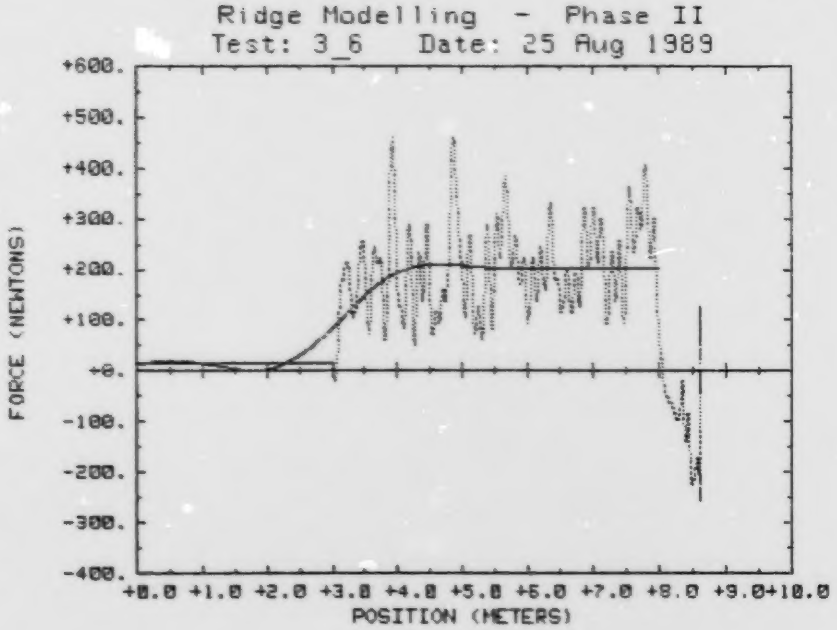


RIDGE MODELLING for 3 6
FORCE (NEWTONS)
600
400
200
0
-200
-400
15
20
25
30
35
Time (sec)

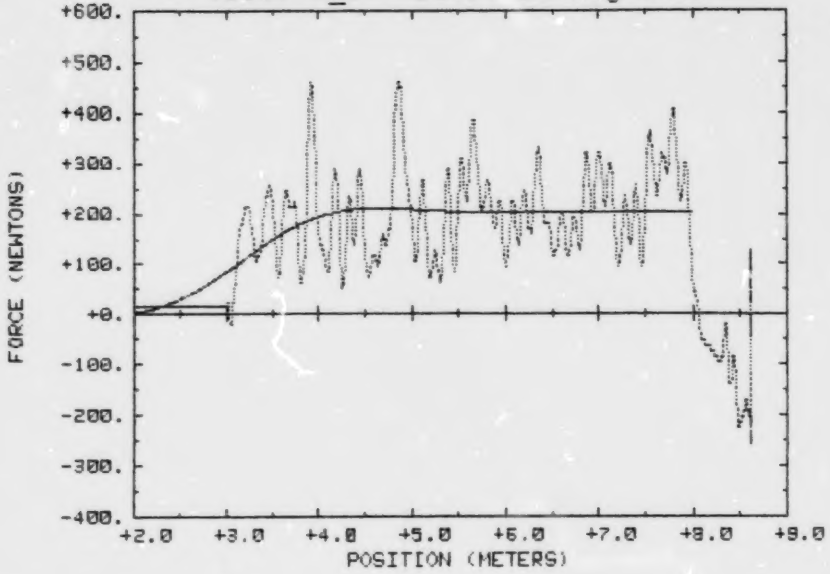


RIDGE MODELLING for 3 6
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
Time (sec)

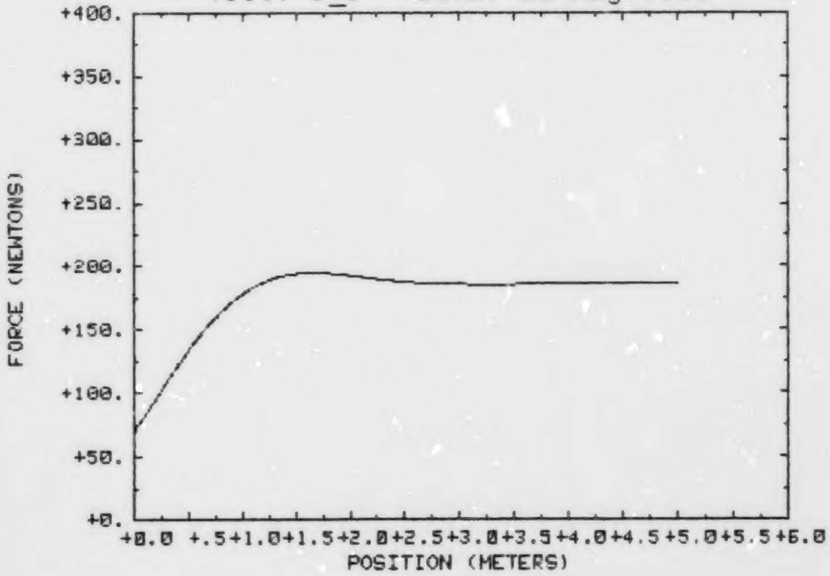

RIDGE MODELLING
Project:3165C Test:3_6
FORCE (NEWTONS)
+600.
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

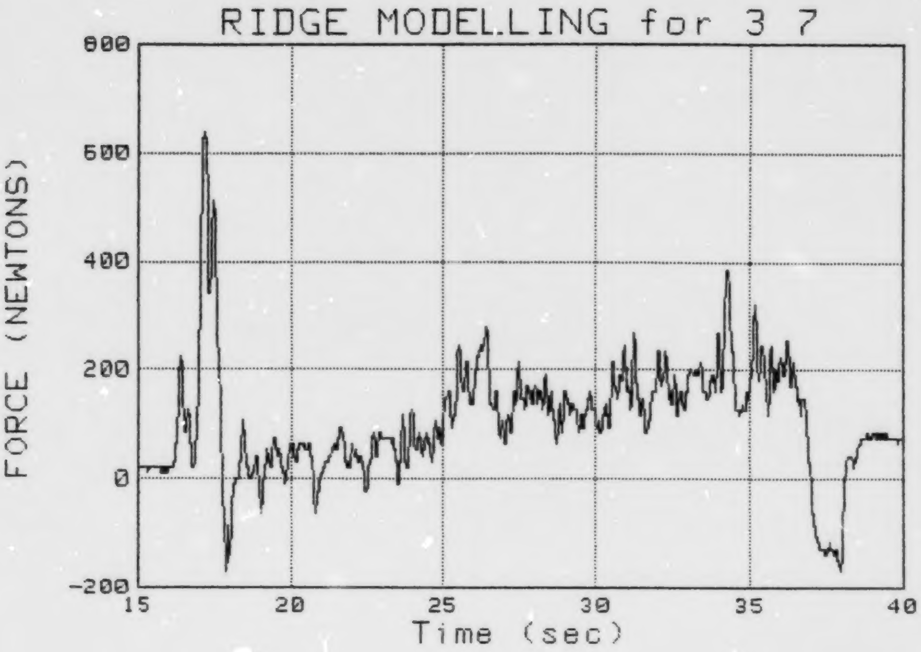

Ridge Modelling - Phase II
Test: 3_6 Date: 25 Aug 1989
FORCE (NEWTONS)
+600.
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

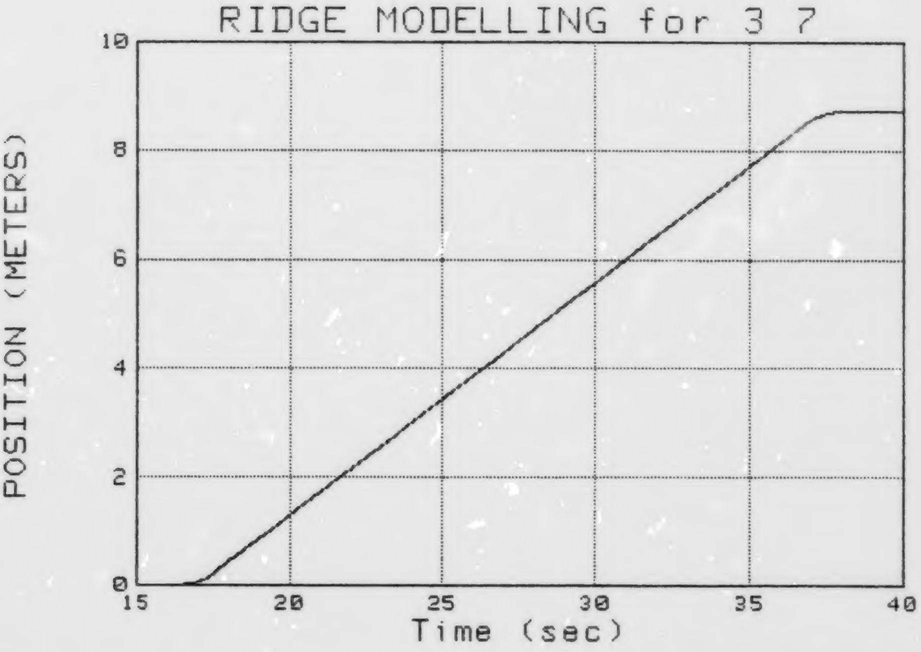
Ridge Modelling - Phase II
Test: 3_6 Date: 25 Aug 1989

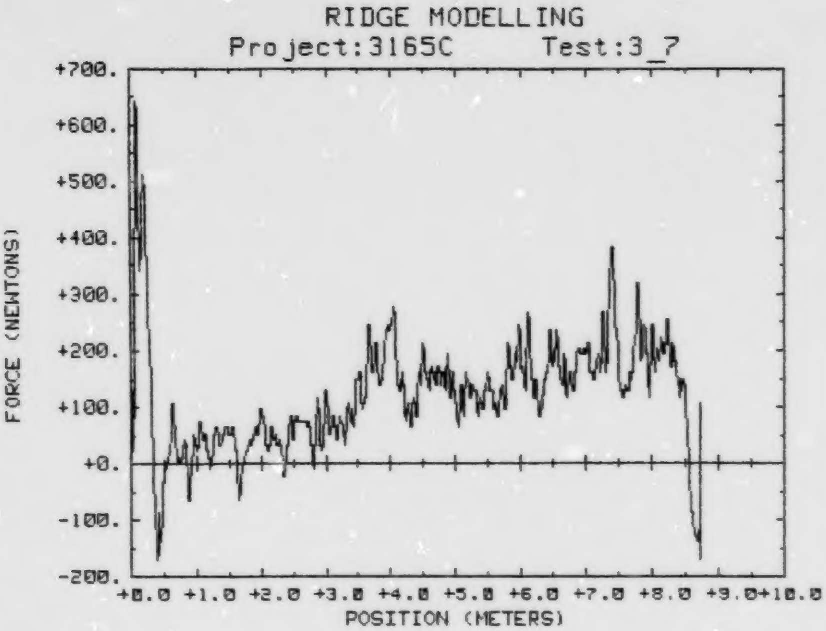


Ridge Modelling - Phase II
Test: 3_6 Date: 25 Aug 1989

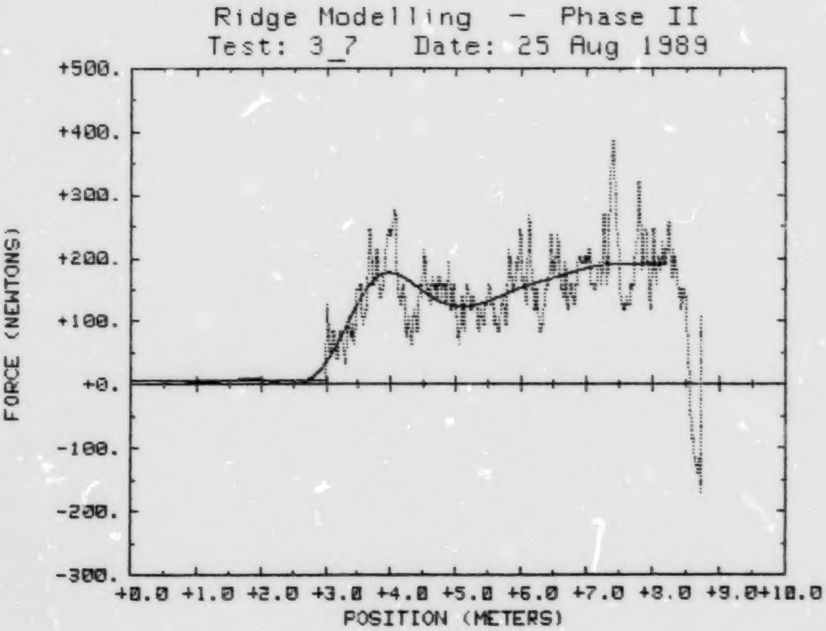



RIDGE MODELLING for 3 7
FORCE (NEWTONS)
800
600
400
200
0
-200
15
20
25
30
35
40
Time (sec)

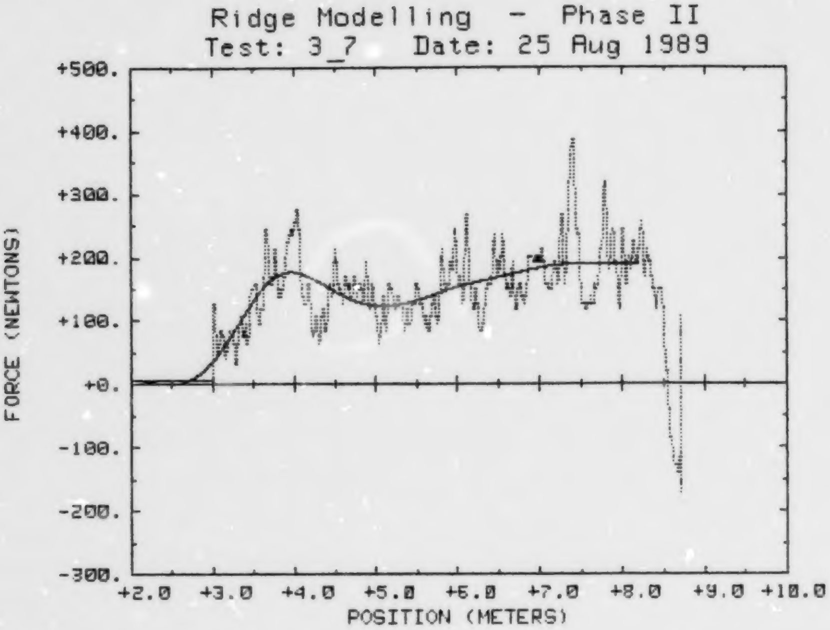

RIDGE MODELLING for 3 7
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
Time (sec)

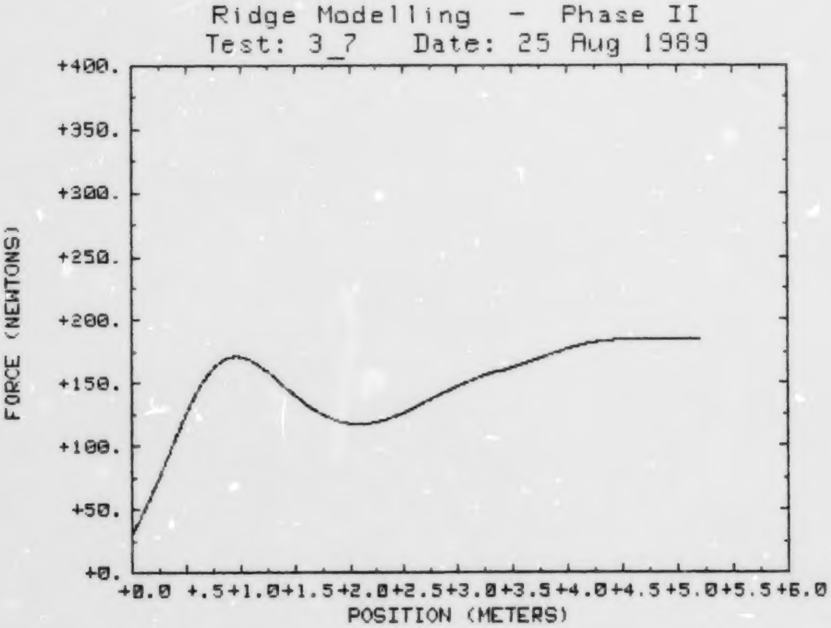


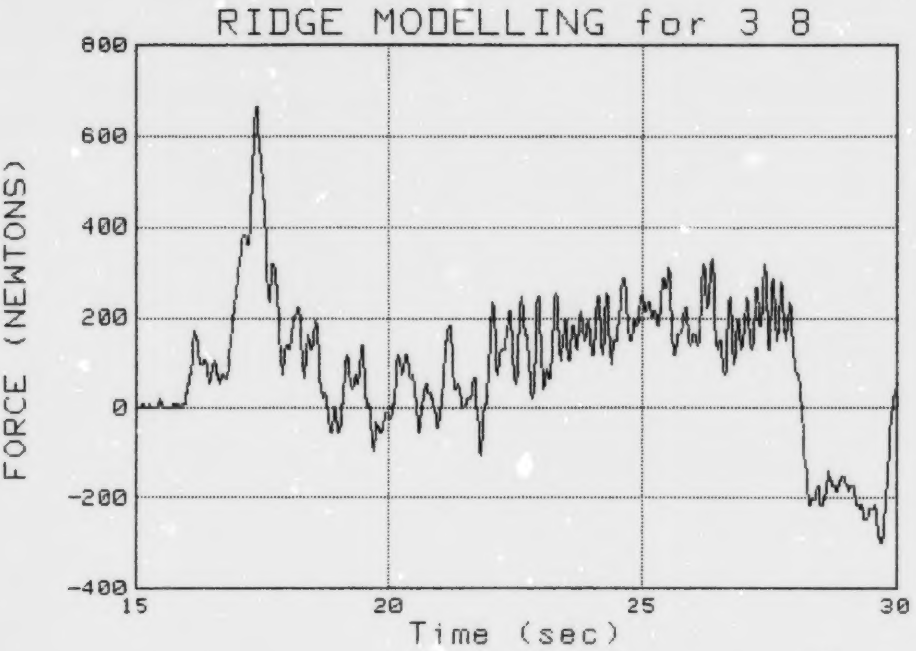
RIDGE MODELLING
Project:3165C Test:3_7

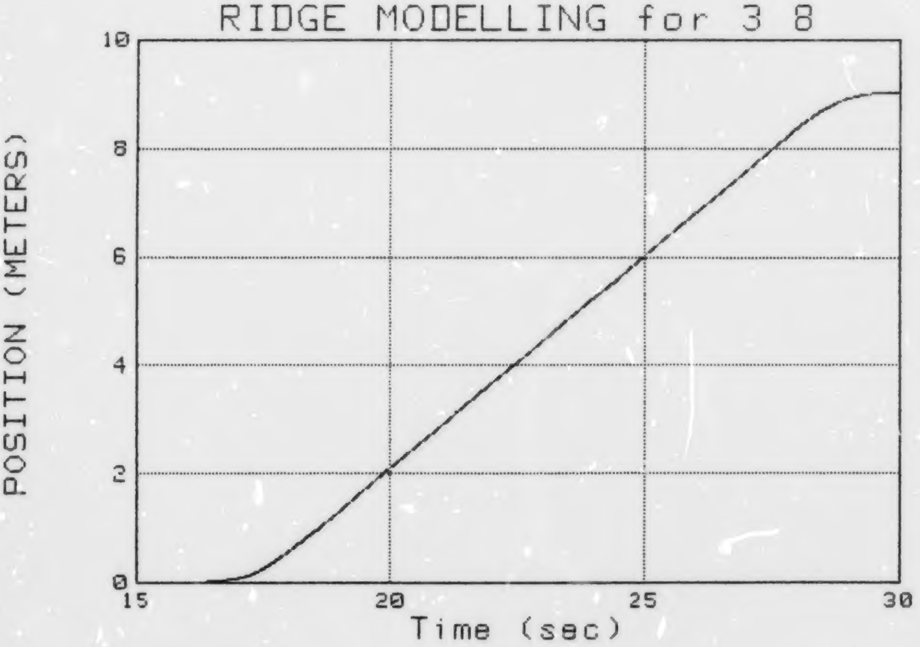


Ridge Modelling - Phase II
Test: 3_7 Date: 25 Aug 1989

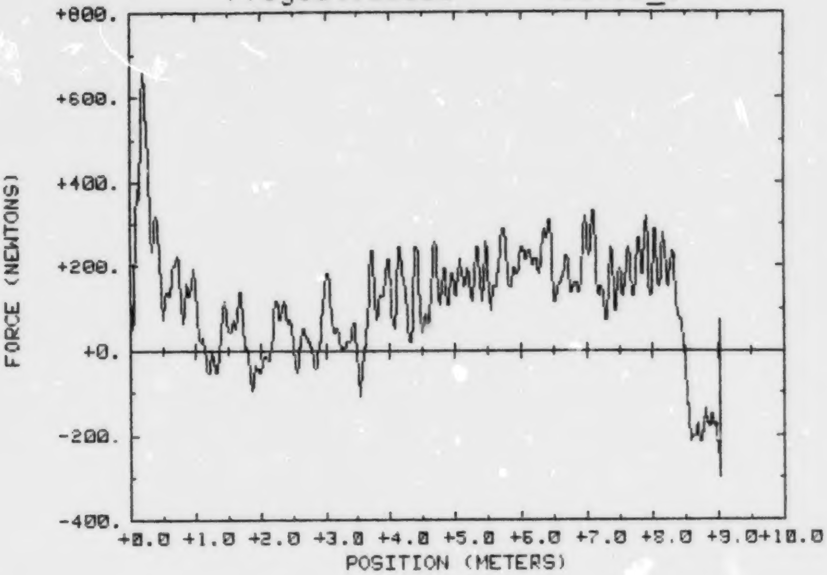

Ridge Modelling - Phase II
Test: 3_7 Date: 25 Aug 1989
FORCE (NEWTONS)
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 3_7 Date: 25 Aug 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

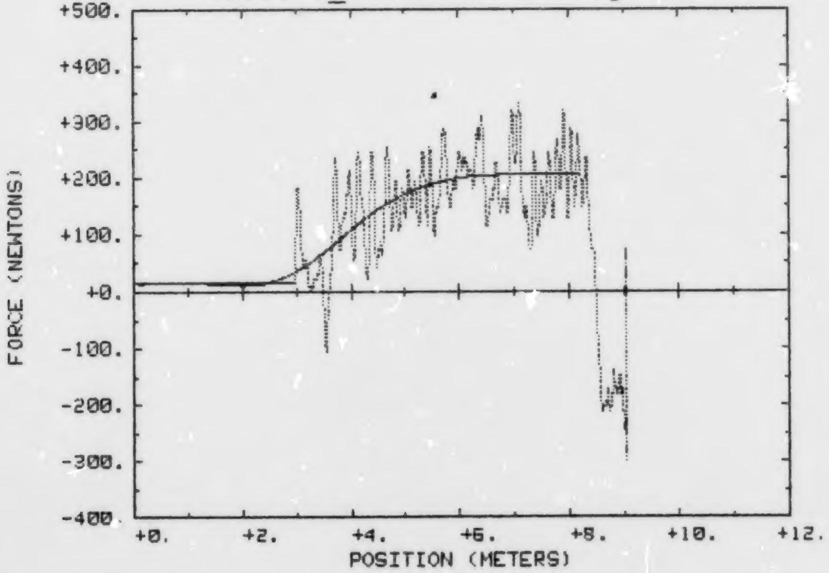

RIDGE MODELLING for 3 8


RIDGE MODELLING for 3 8

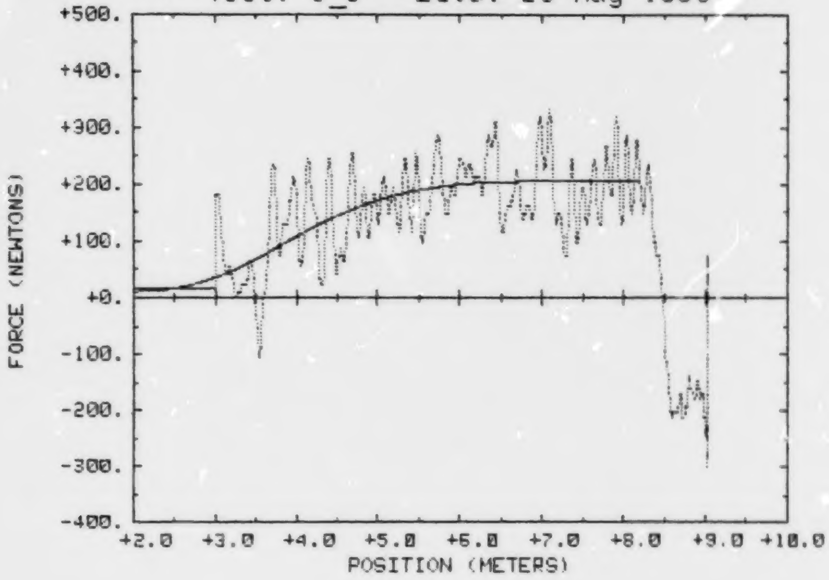
RIDGE MODELLING
Project:3165C Test:3_8



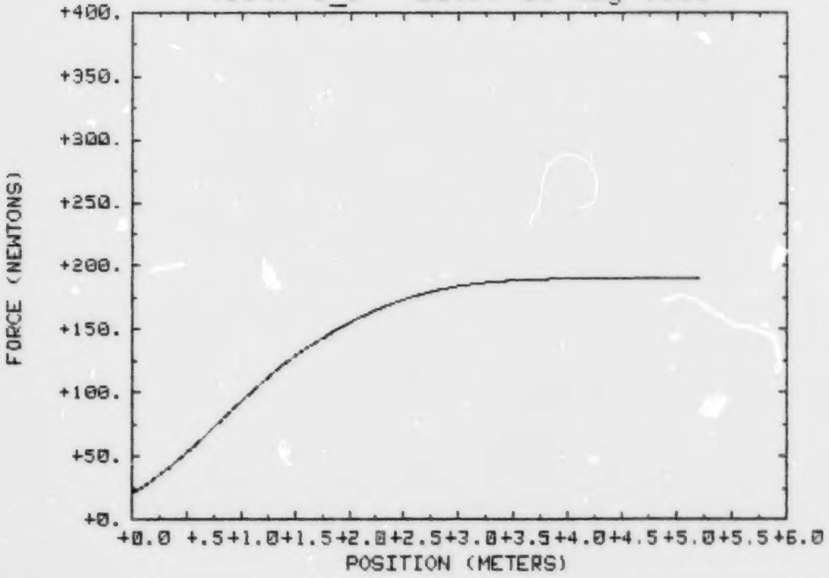
Ridge Modelling - Phase II
Test: 3_8 Date: 25 Aug 1989

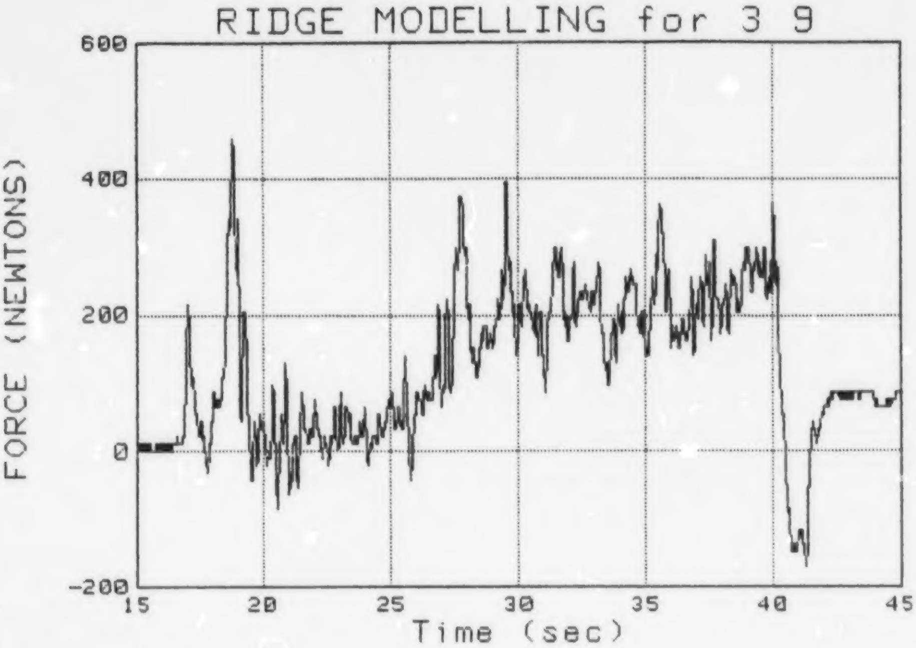


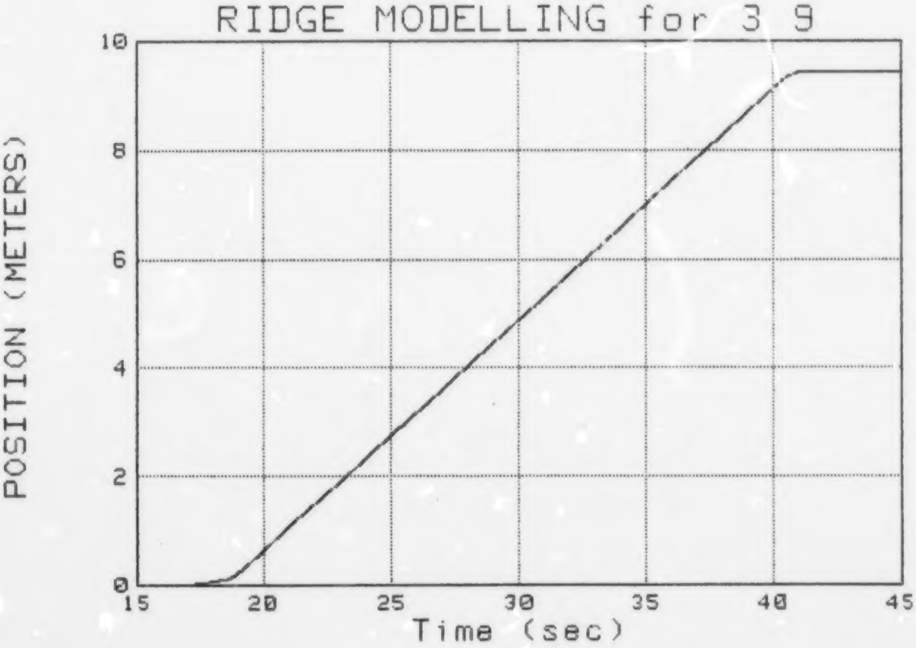
Ridge Modelling - Phase II
Test: 3_8 Date: 25 Aug 1989



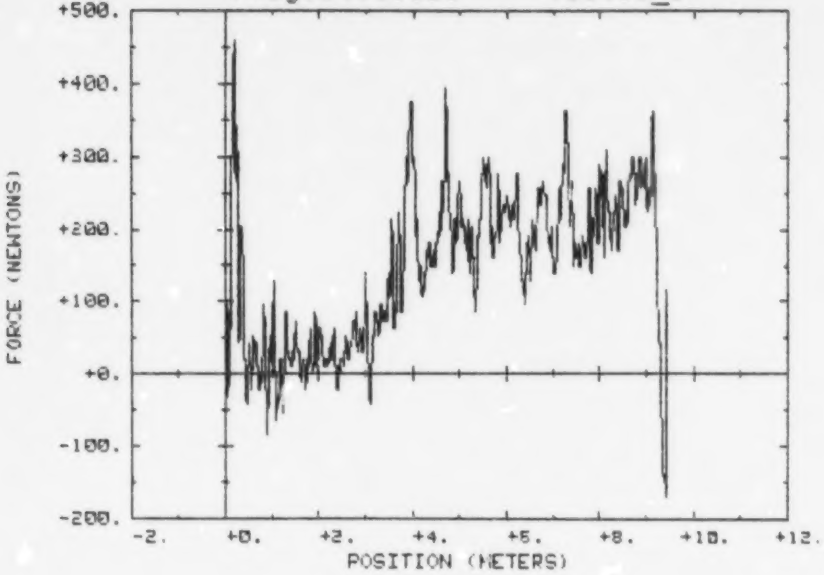
Ridge Modelling - Phase II
Test: 3_8 Date: 25 Aug 1989



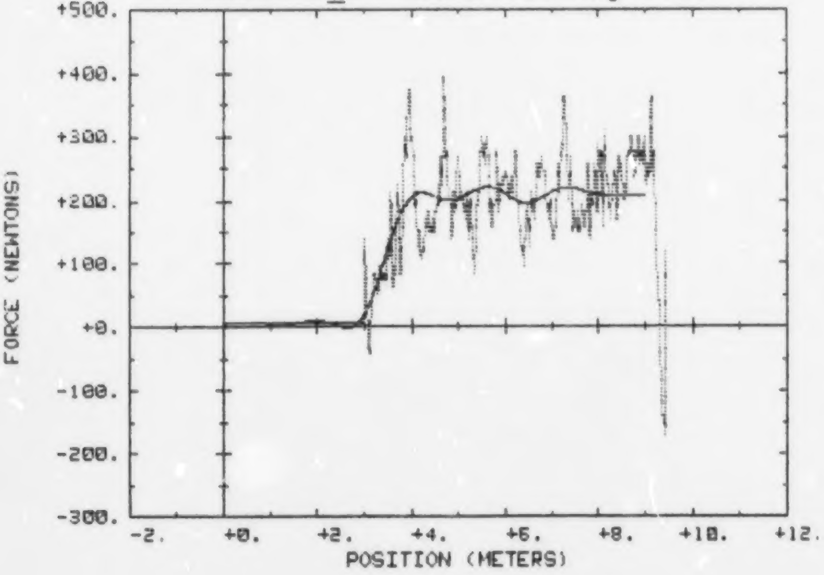

RIDGE MODELLING for 3 9
FORCE (NEWTONS)
600
400
200
0
-200
15
20
25
30
35
40
45
Time (sec)

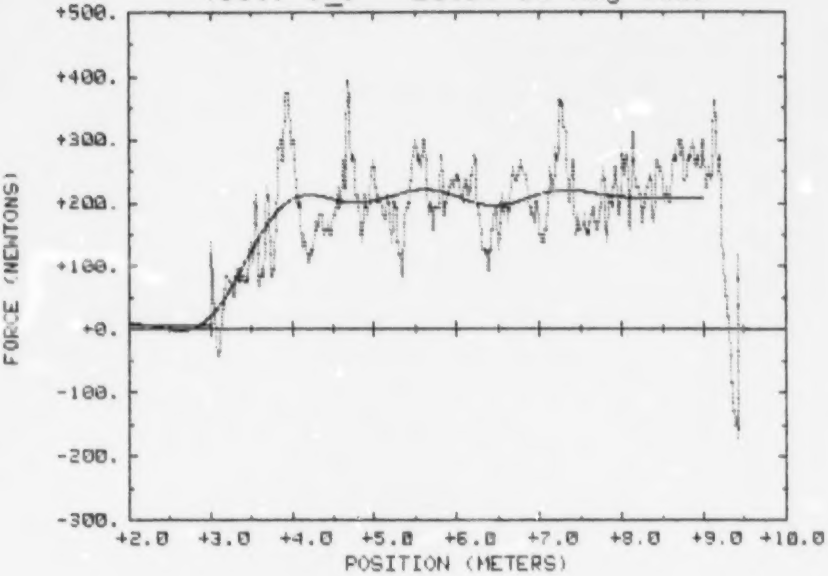

RIDGE MODELLING for 3 9
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
45
Time (sec)

RIDGE MODELLING
Project:3165C Test:3_9

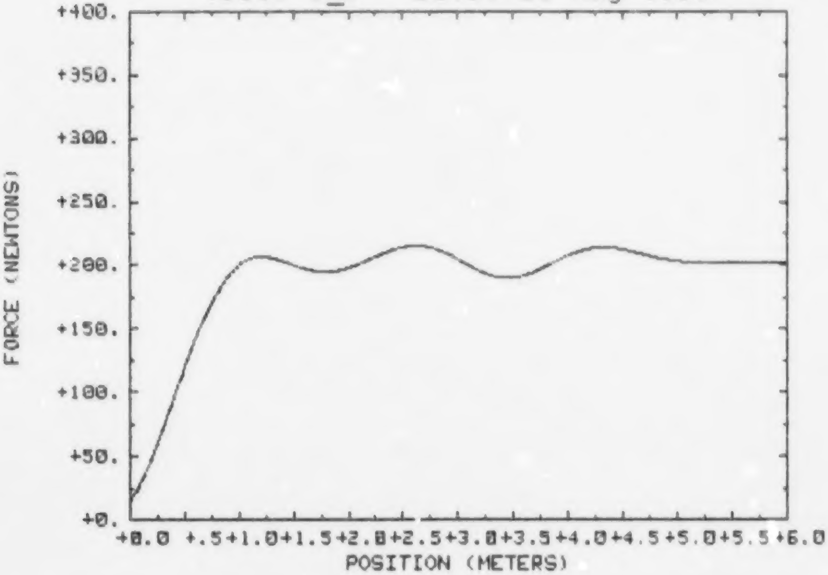


Ridge Modelling - Phase II
Test: 3_9 Date: 25 Aug 1989

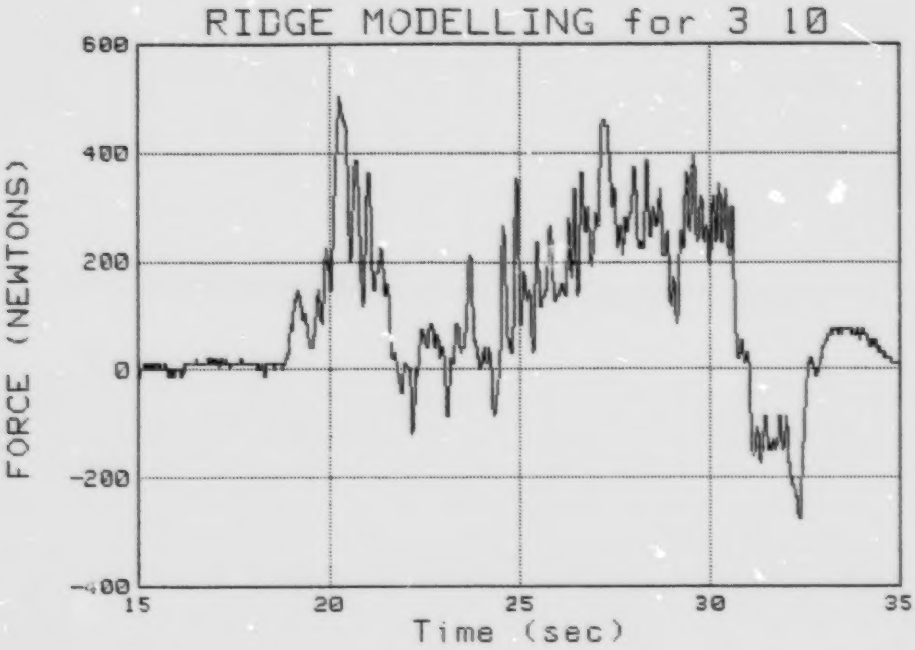




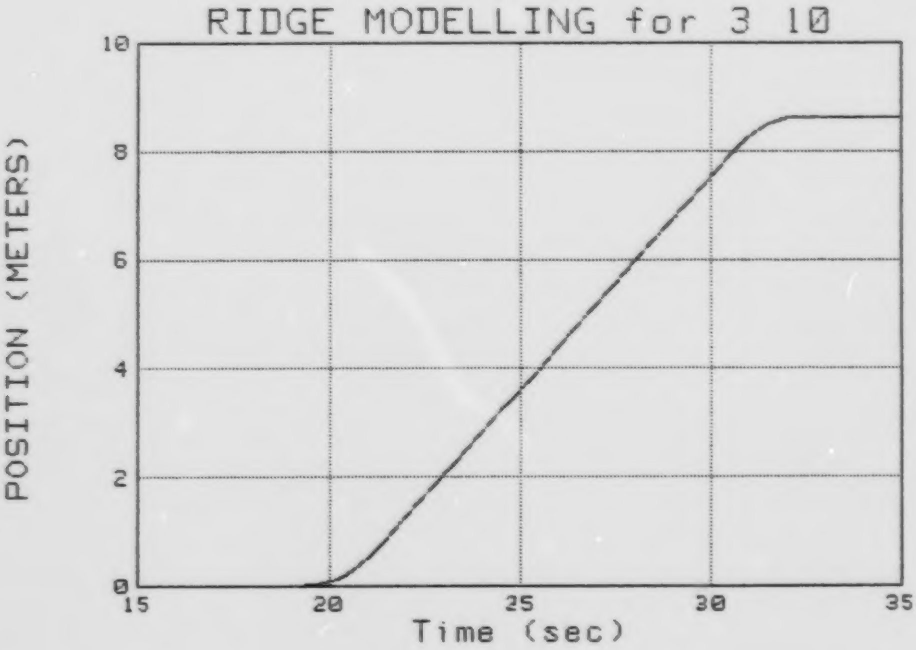
Ridge Modelling - Phase II
Test: 3_9 Date: 25 Aug 1989



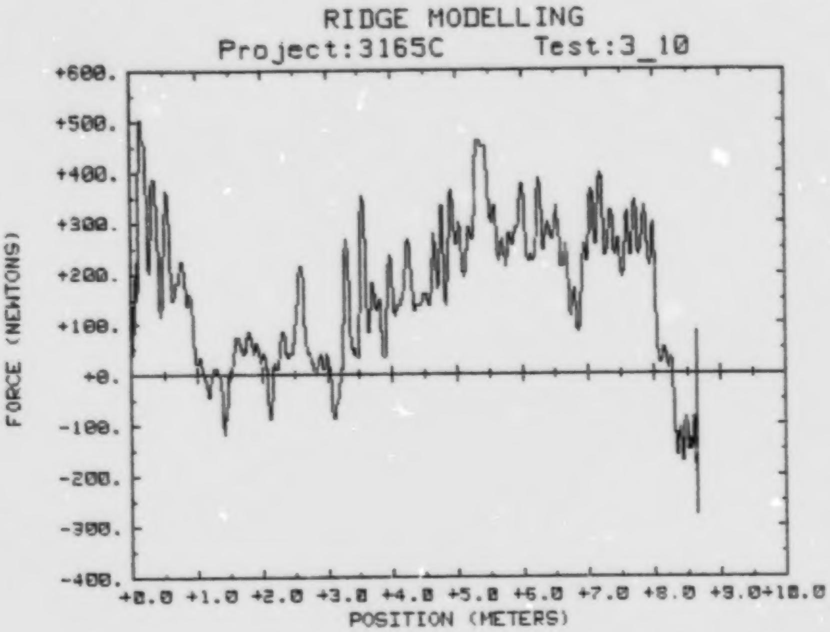
Ridge Modelling - Phase II
Test: 3_9 Date: 25 Aug 1989

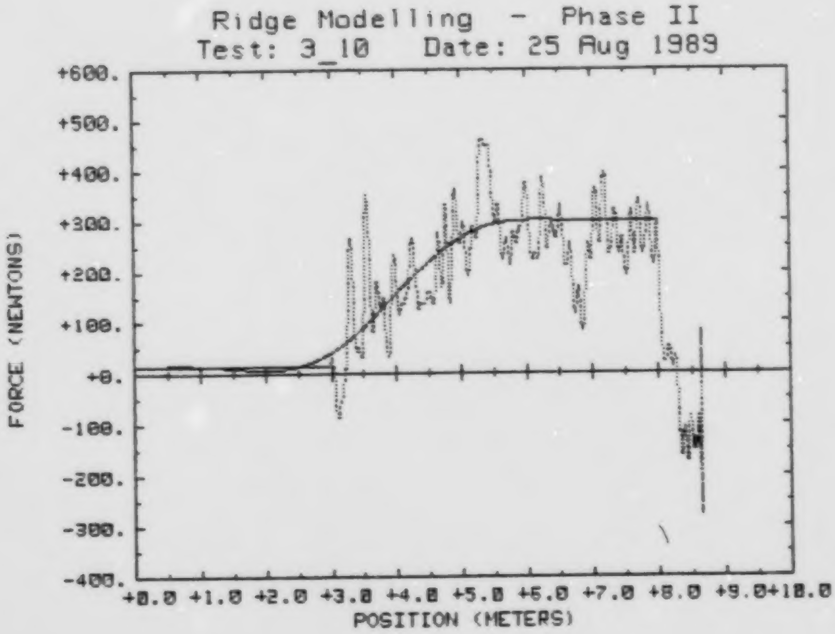


RIDGE MODELLING for 3 10

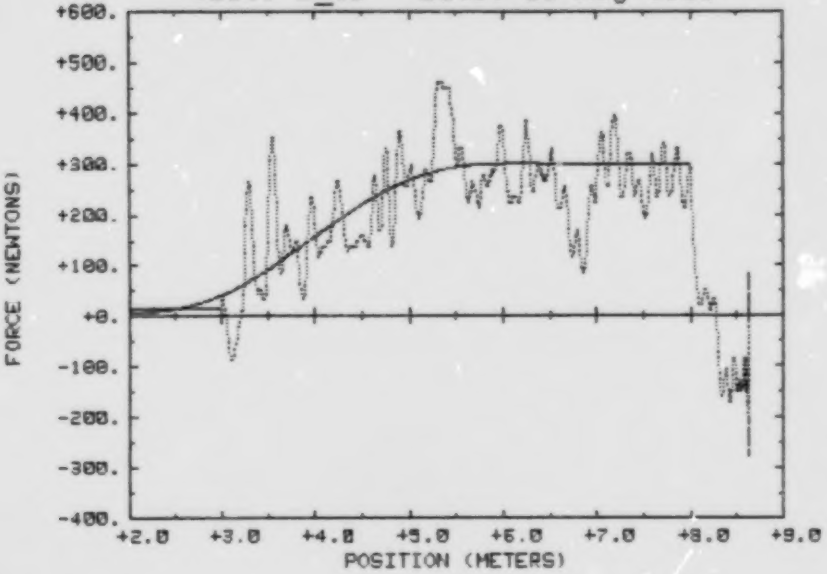


RIDGE MODELLING for 3 10

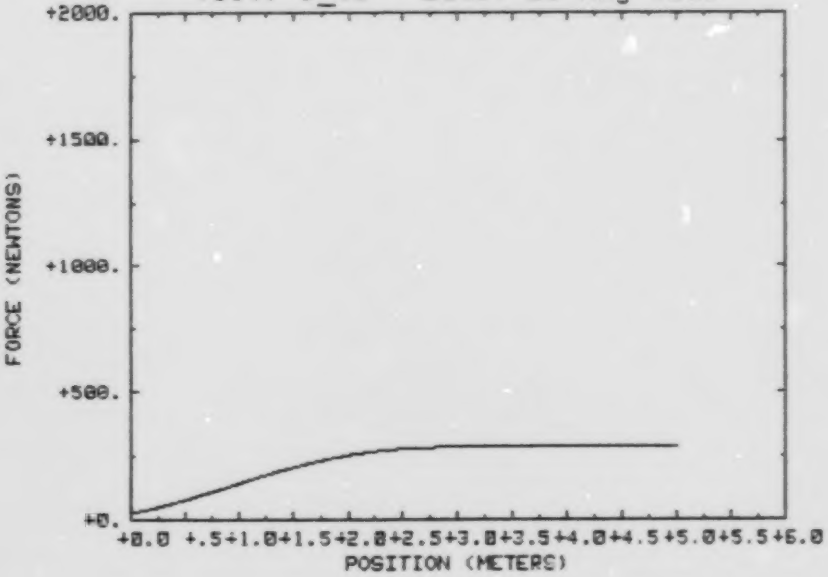

RIDGE MODELLING
Project:3165C Test:3_10

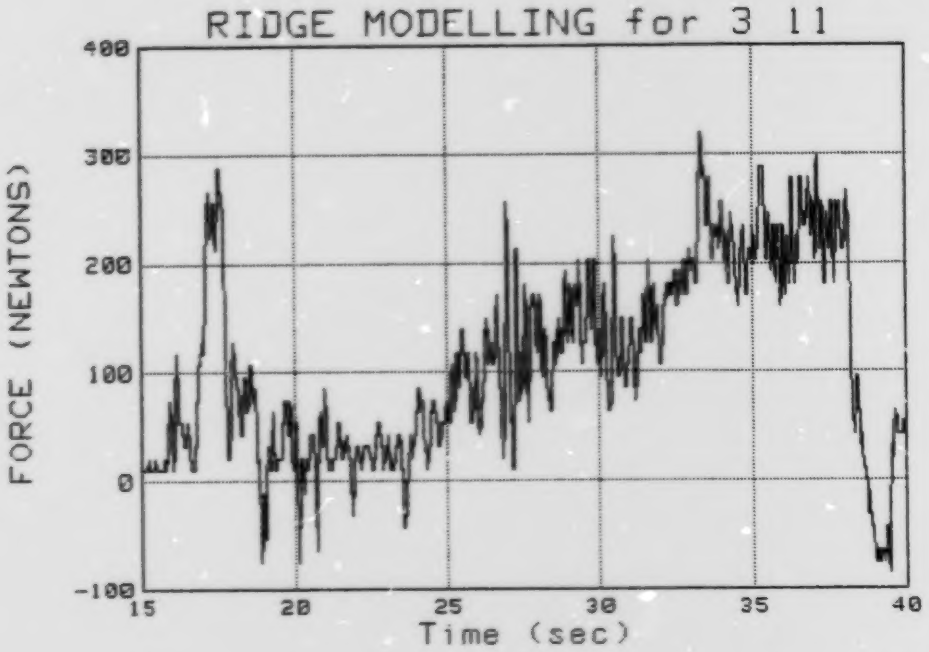

Ridge Modelling - Phase II
Test: 3_10 Date: 25 Aug 1989

Ridge Modelling - Phase II
Test: 3_10 Date: 25 Aug 1989

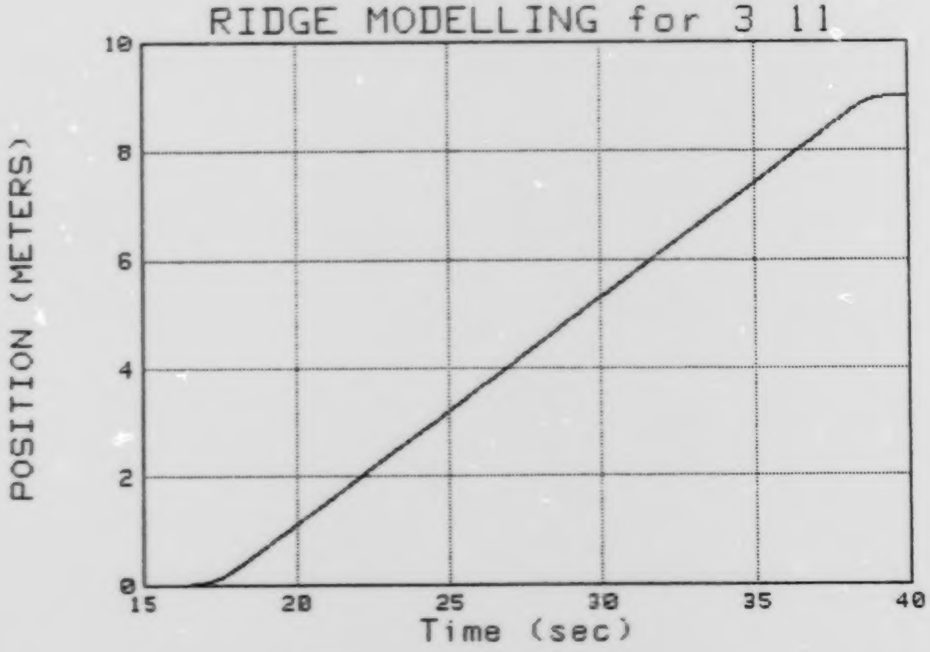


Ridge Modelling - Phase II
Test: 3_10 Date: 25 Aug 1989



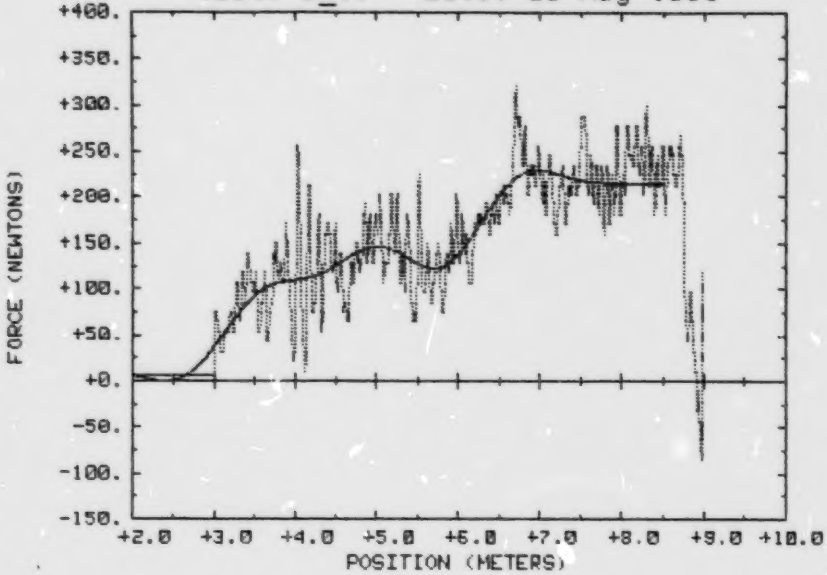


RIDGE MODELLING for 3 11

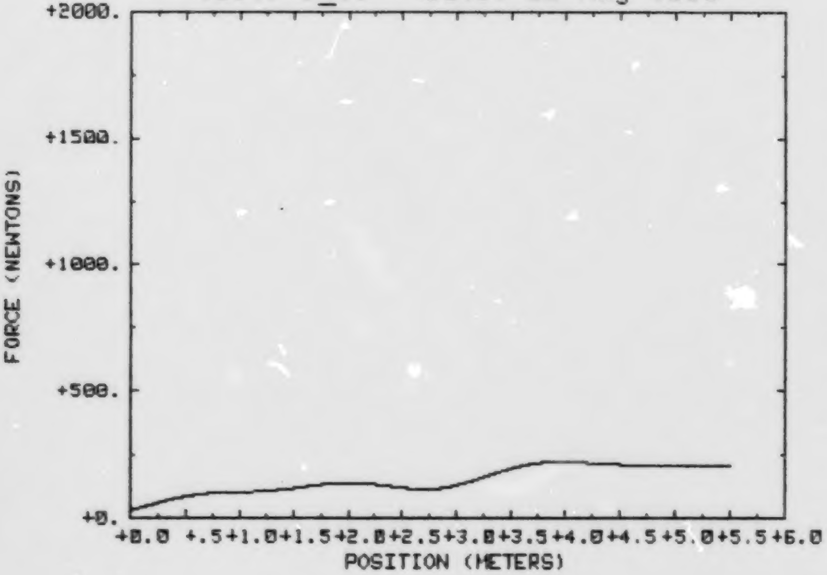


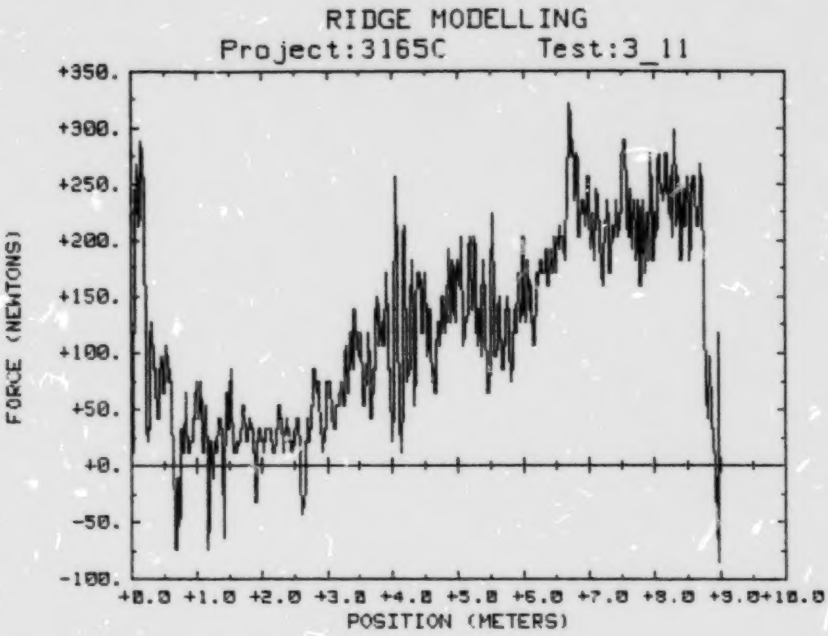
RIDGE MODELLING for 3 11

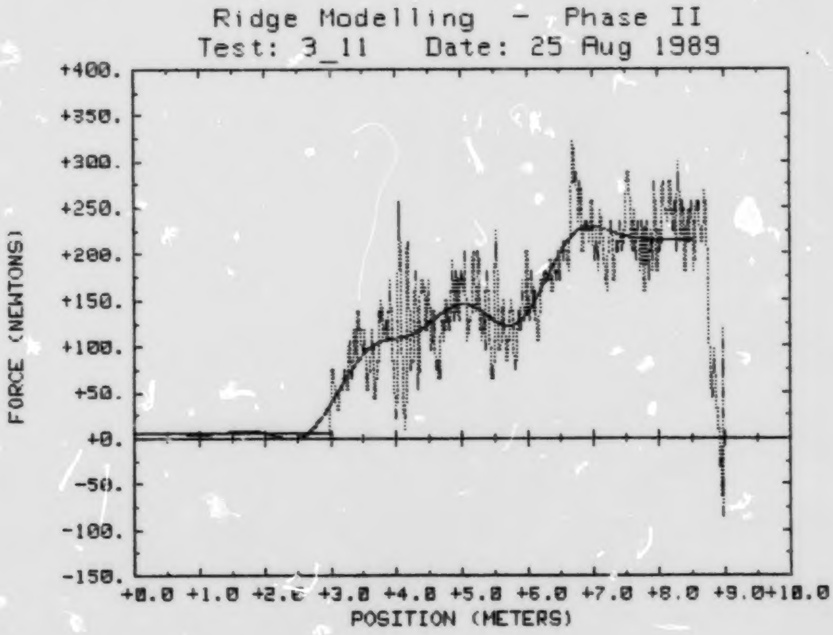
Ridge Modelling - Phase II
Test: 3_11 Date: 25 Aug 1989

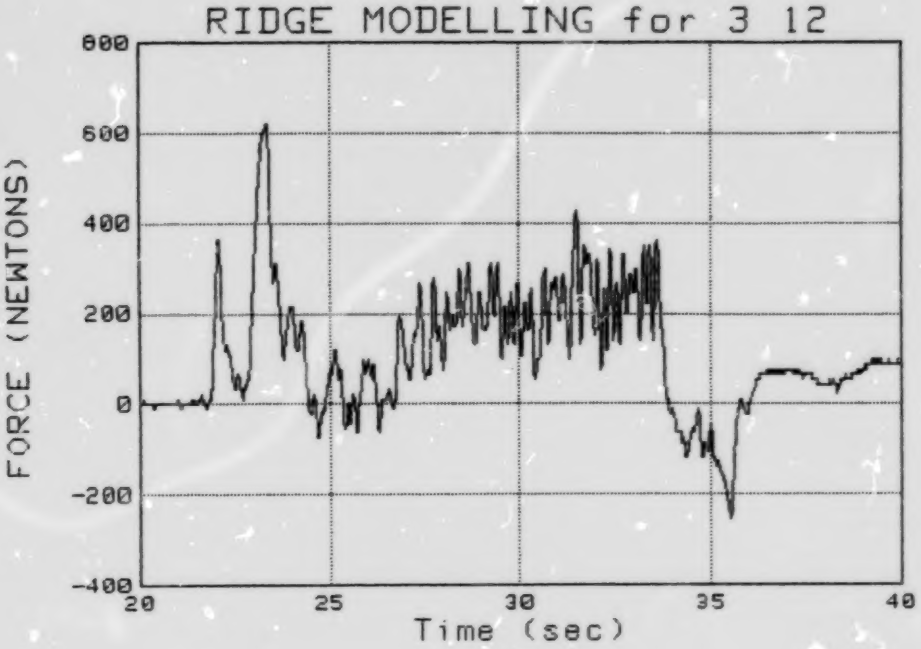


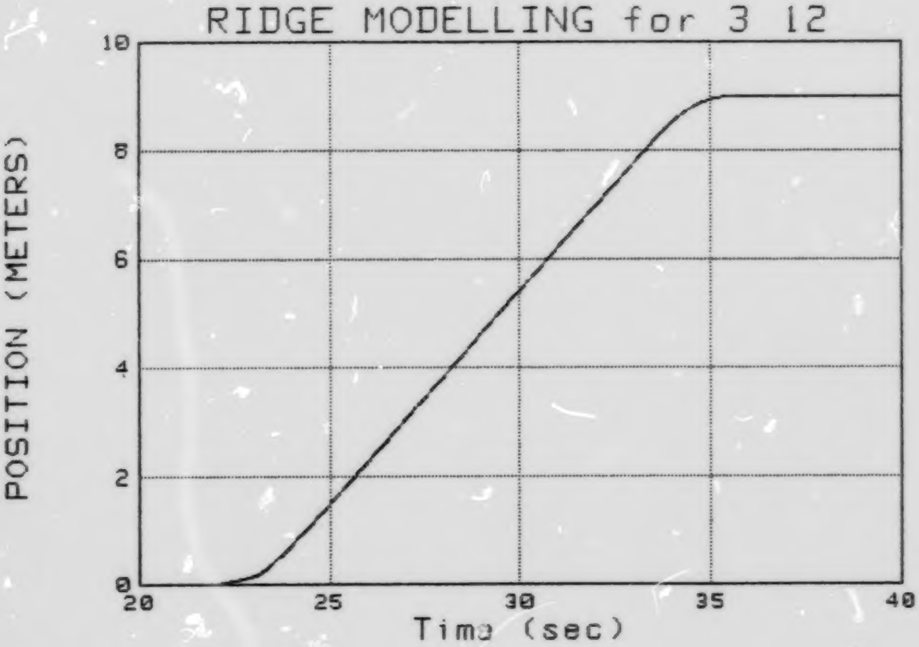
Ridge Modelling - Phase II
Test: 3_11 Date: 25 Aug 1989

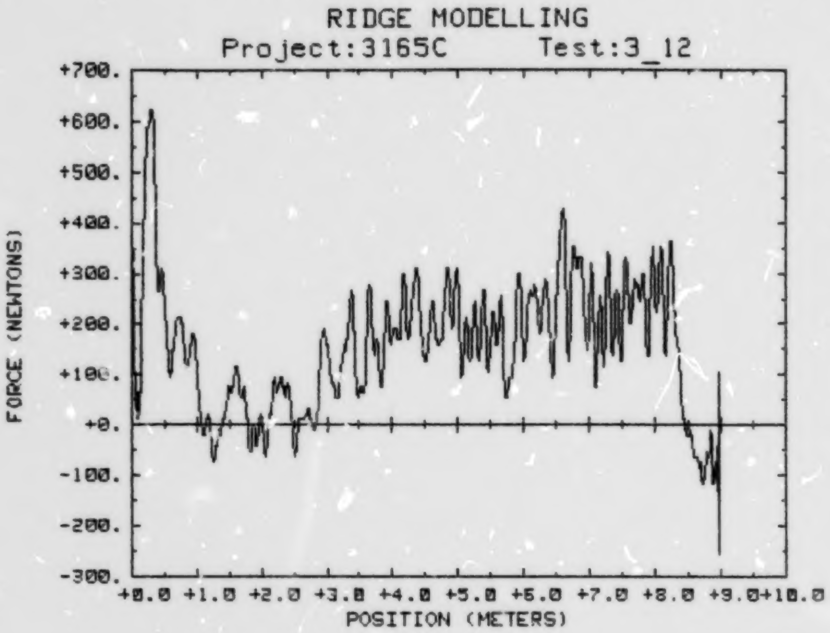


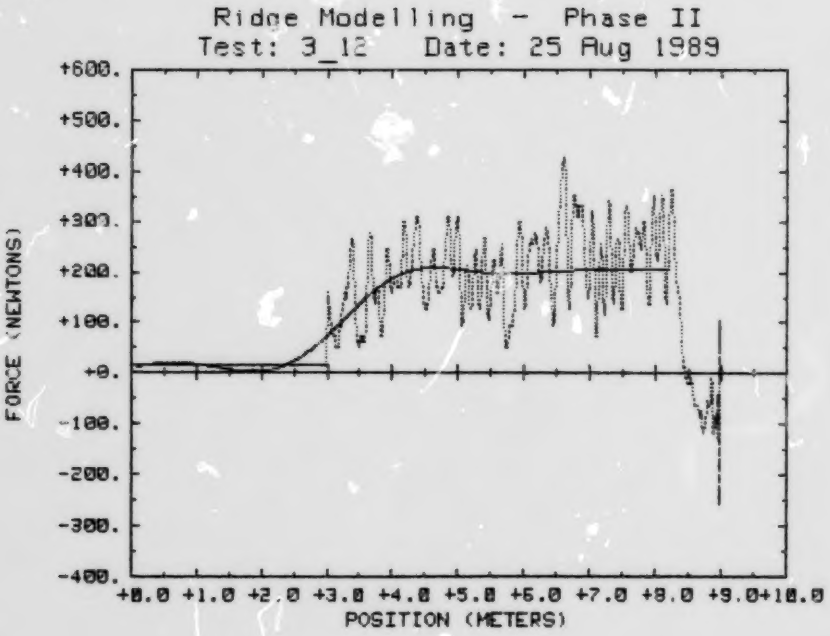

RIDGE MODELLING
Project:3165C Test:3_11
FORCE (NEWTONS)
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 3_11 Date: 25 Aug 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

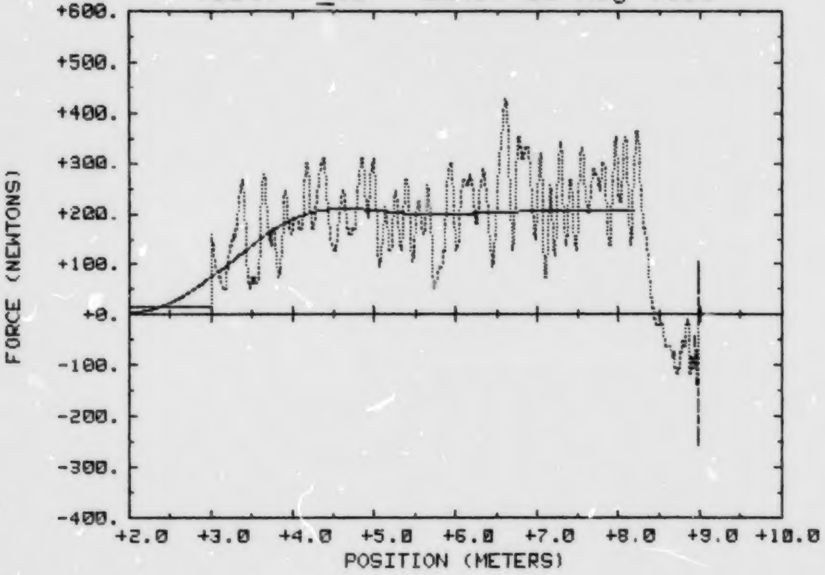

RIDGE MODELLING for 3 12


RIDGE MODELLING for 3 12

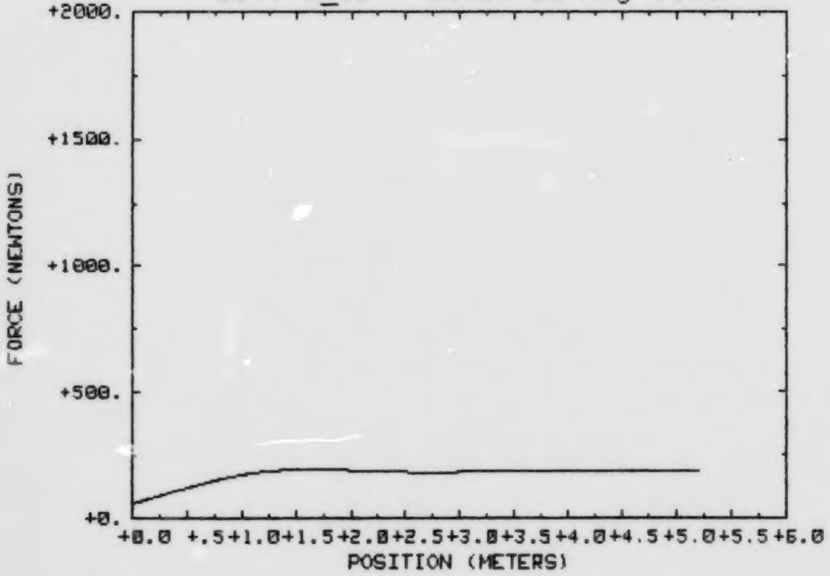

RIDGE MODELLING
Project:3165C Test:3_12
FORCE (NEWTONS)
+700.
+600.
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 3_12 Date: 25 Aug 1989
FORCE (NEWTONS)
+600.
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

Ridge Modelling - Phase II
Test: 3_12 Date: 25 Aug 1989

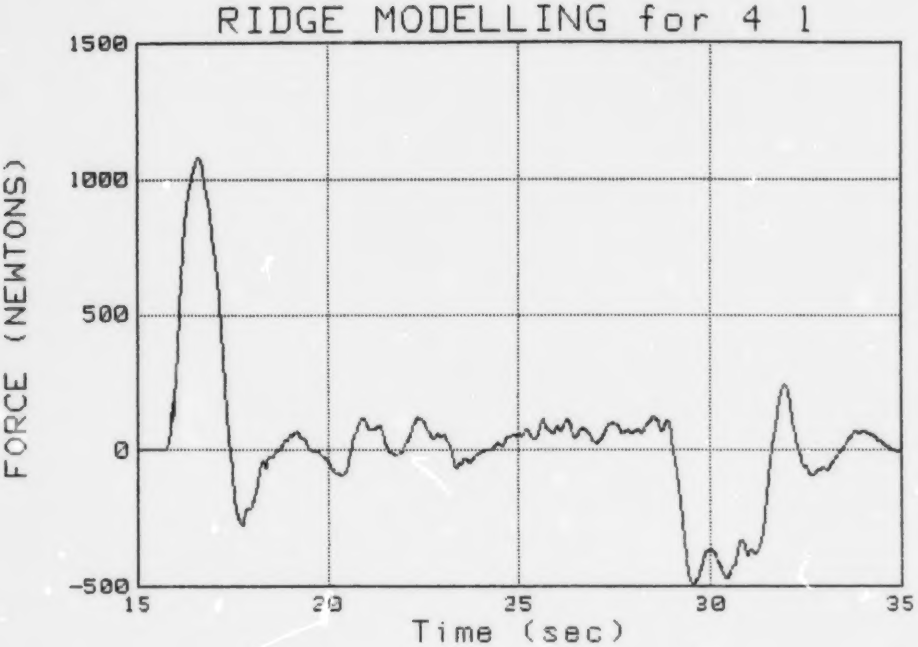


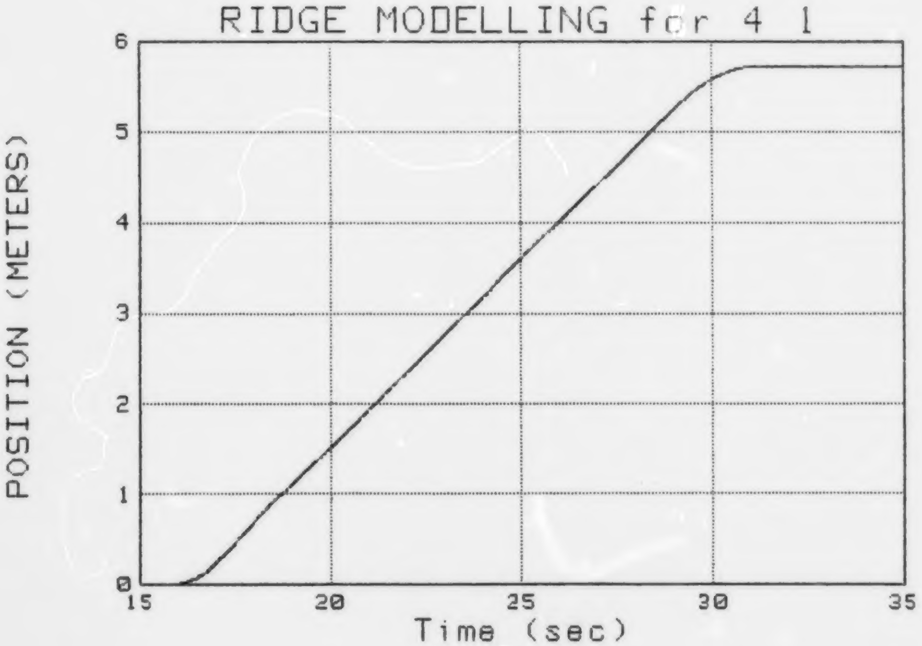
Ridge Modelling - Phase II
Test: 3_12 Date: 25 Aug 1989

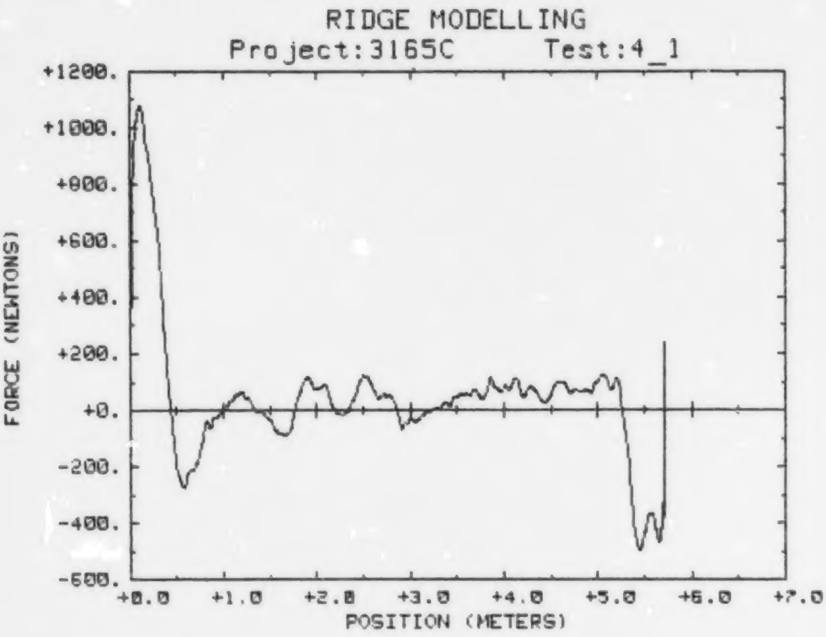


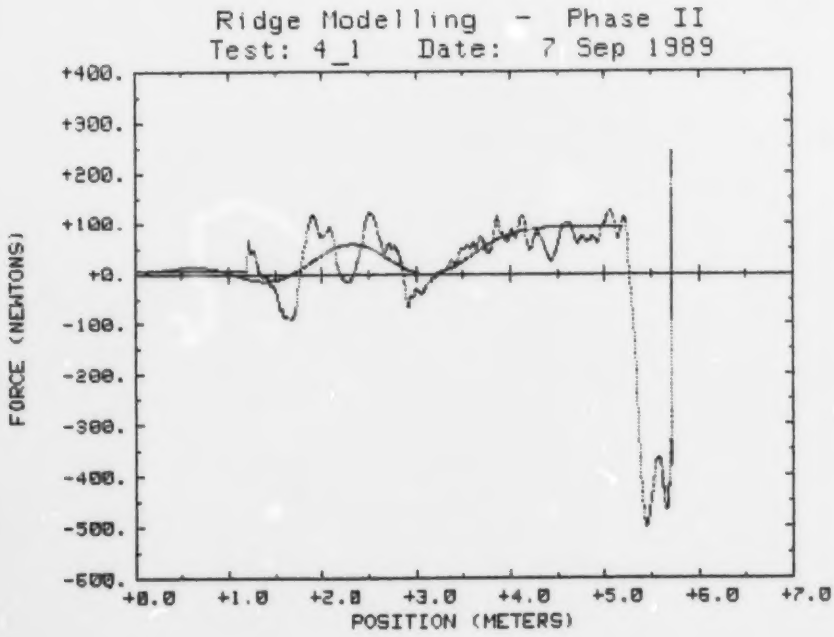
APPENDIX D

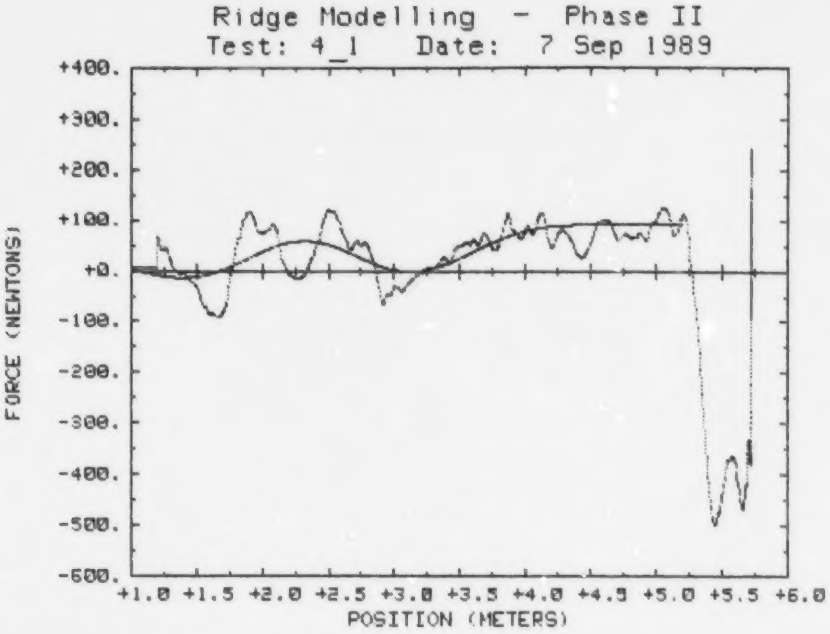
TEST DATA FOR SHEET #4

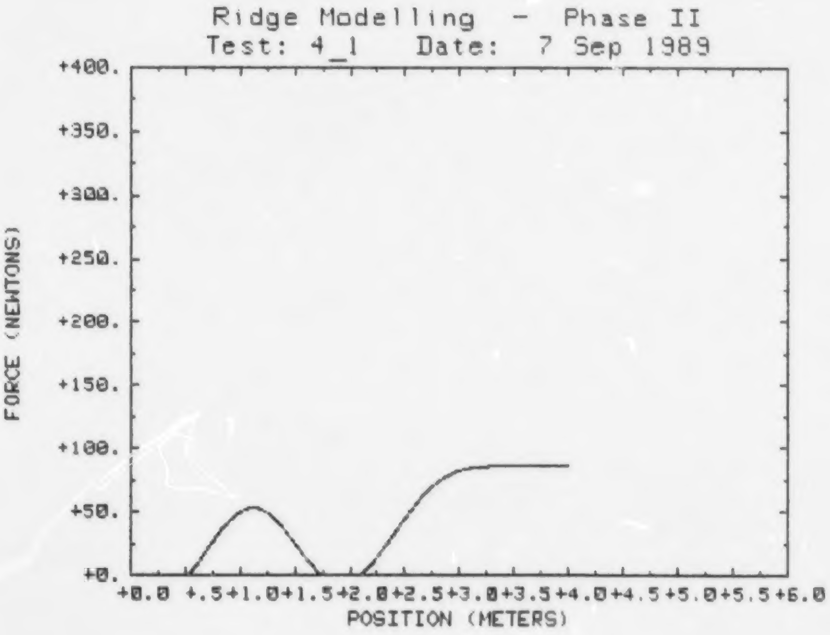

RIDGE MODELLING for 4 1
FORCE (NEWTONS)
1500
1000
500
0
-500
15
20
25
30
35
Time (sec)

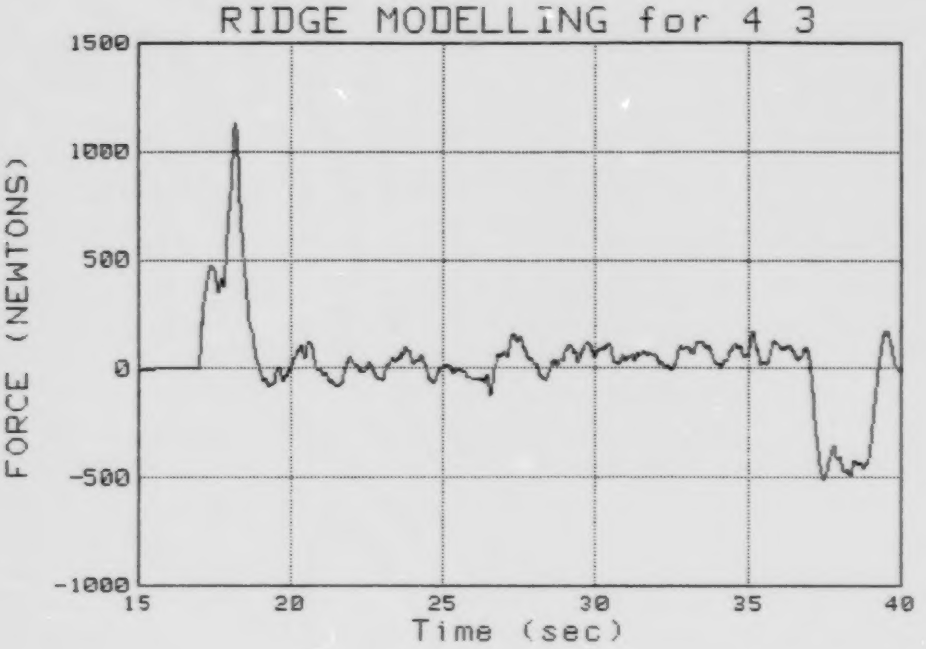

RIDGE MODELLING for 4 1
POSITION (METERS)
6
5
4
3
2
1
0
15
20
25
30
35
Time (sec)

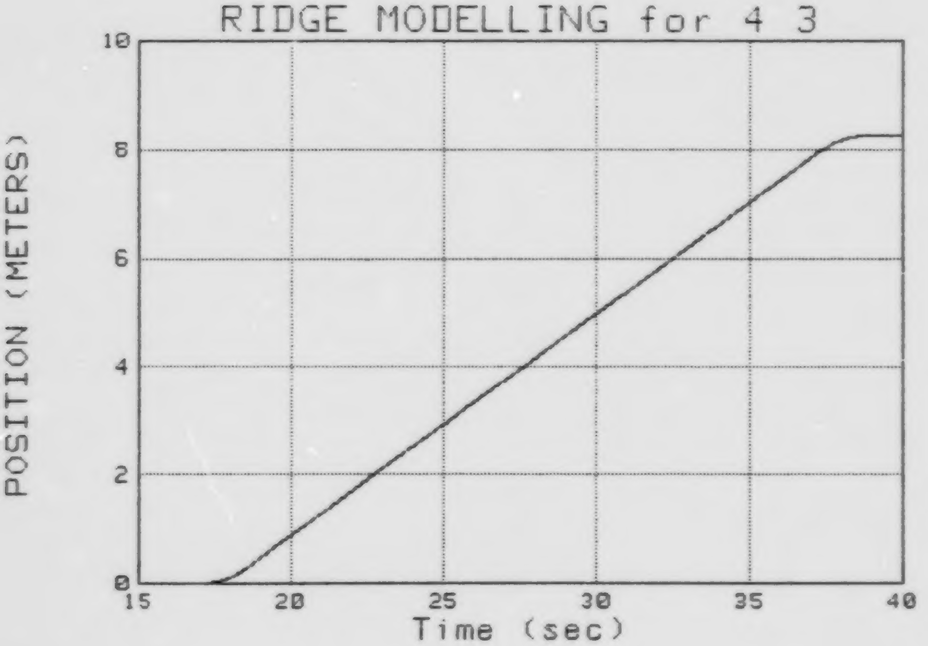

RIDGE MODELLING
Project:3165C Test:4_1
+1200.
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
POSITION (METERS)

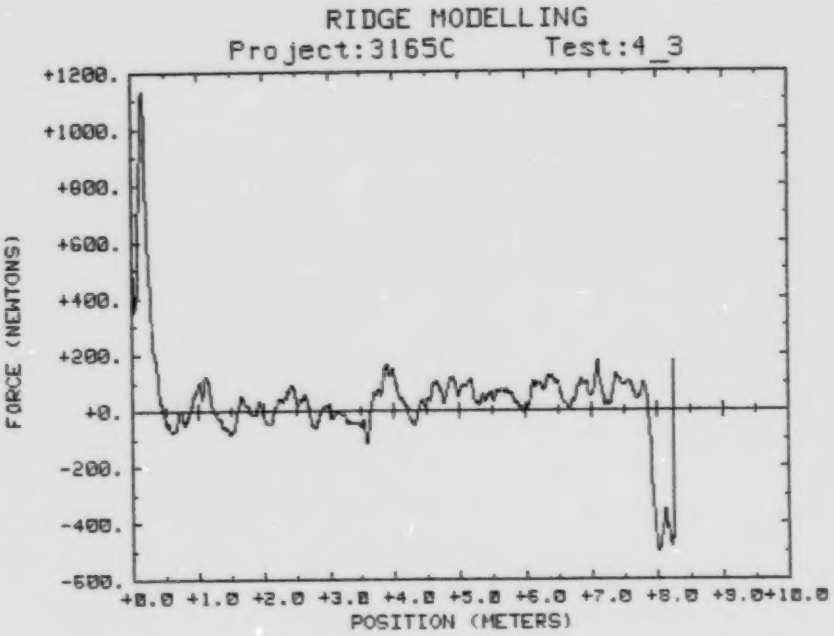

Ridge Modelling - Phase II
Test: 4_1 Date: 7 Sep 1989
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
POSITION (METERS)

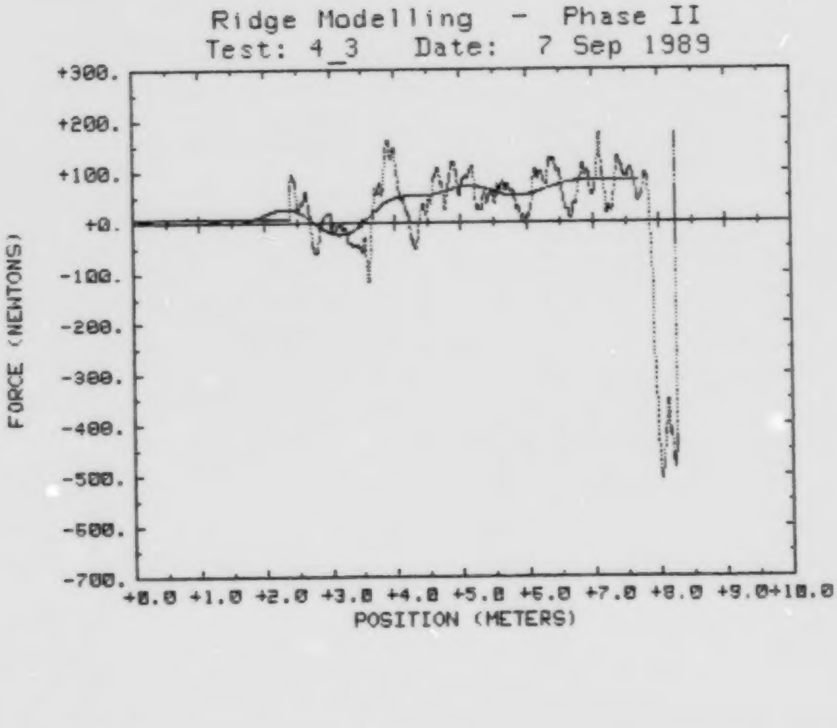

Ridge Modelling - Phase II
Test: 4_1 Date: 7 Sep 1989

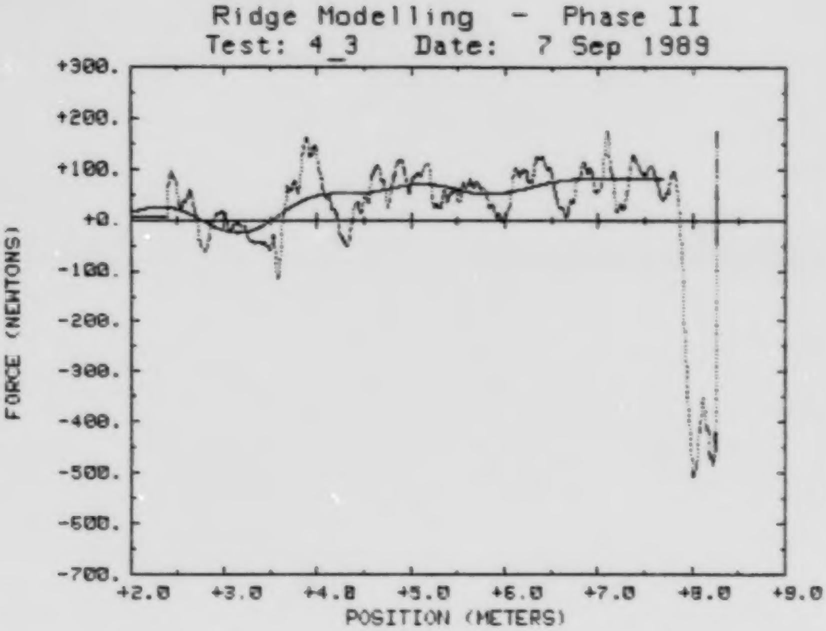

Ridge Modelling - Phase II
Test: 4_1 Date: 7 Sep 1989


RIDGE MODELLING for 4 3
FORCE (NEWTONS)
1500
1000
500
0
-500
-1000
15
20
25
30
35
40
Time (sec)

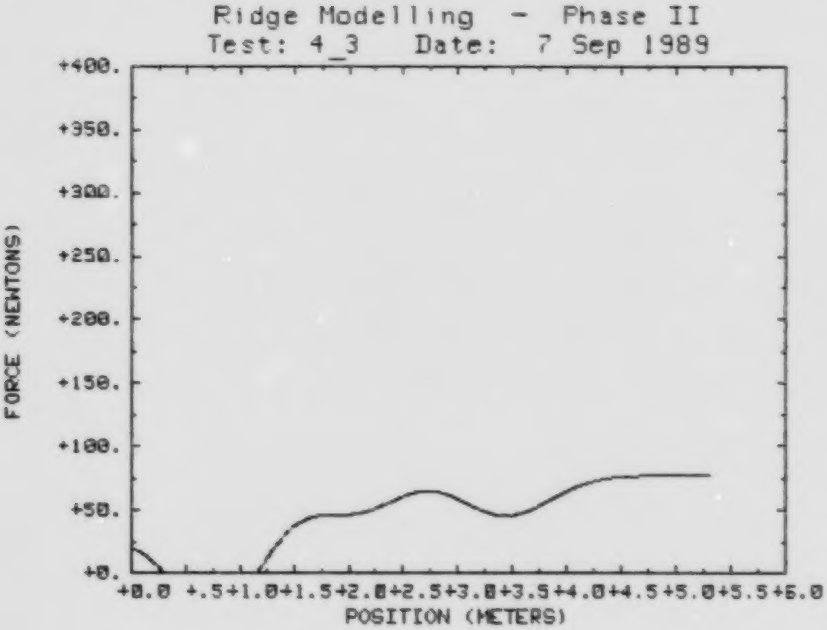

RIDGE MODELLING for 4 3
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
Time (sec)


RIDGE MODELLING
Project:3165C Test:4_3
FORCE (NEWTONS)
+1200.
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 4_3 Date: 7 Sep 1989
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)



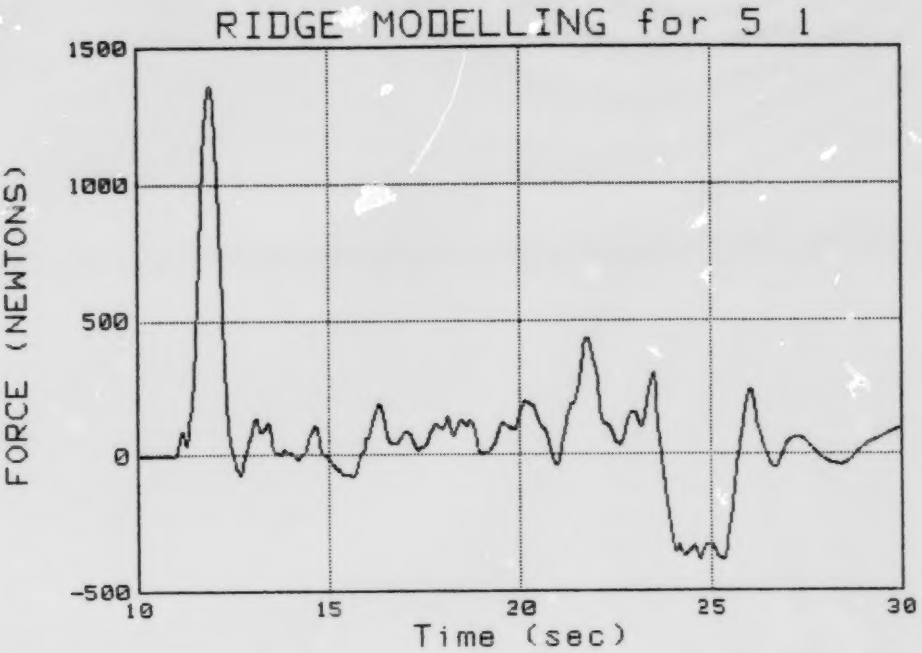
Ridge Modelling - Phase II
Test: 4_3 Date: 7 Sep 1989

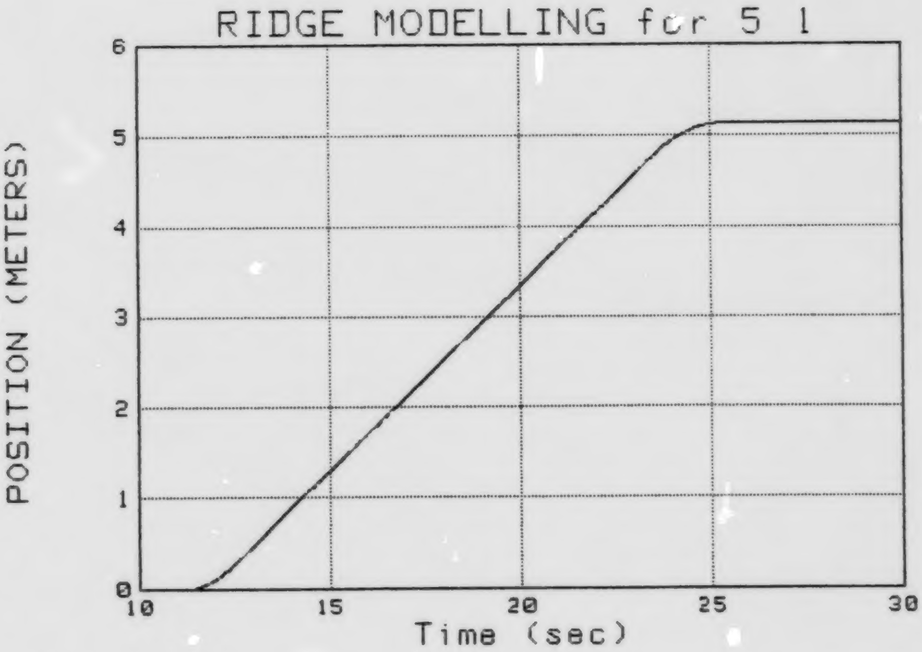


Ridge Modelling - Phase II
Test: 4_3 Date: 7 Sep 1989

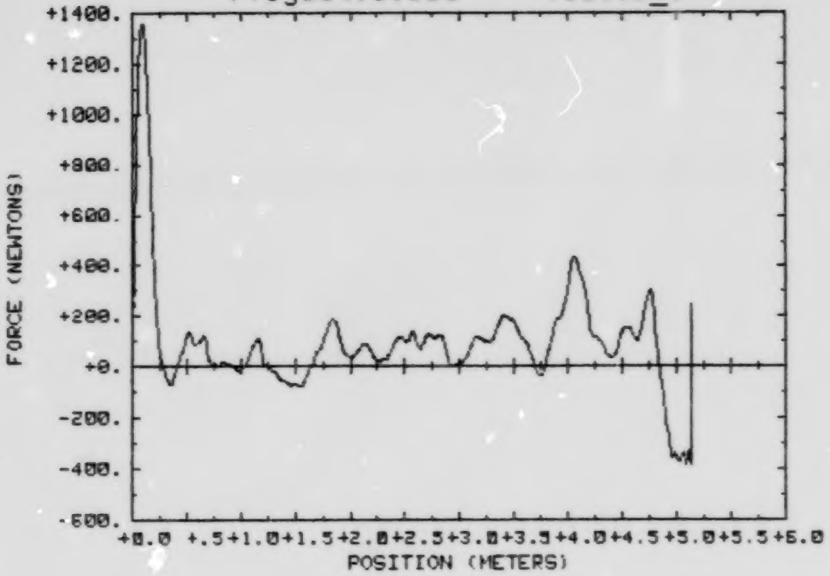
APPENDIX E

TEST DATA FOR SHEET #5

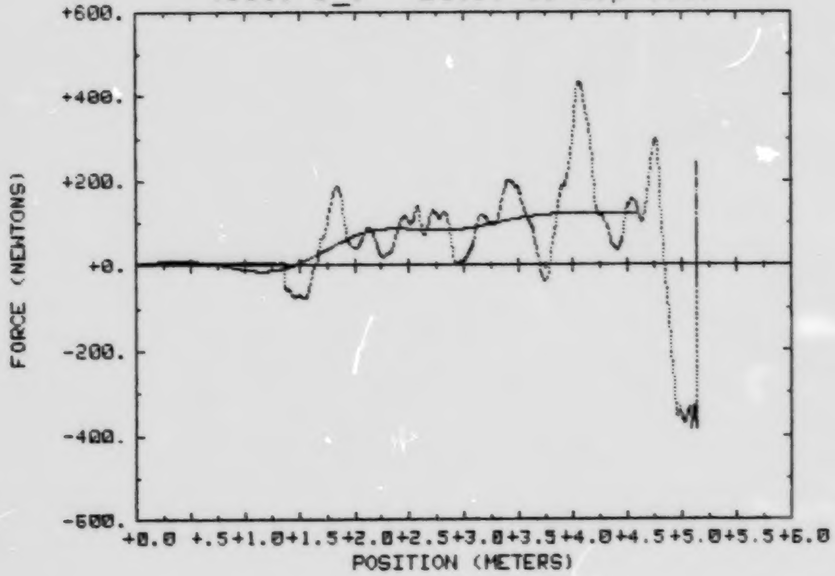

RIDGE MODELLING for 5 1
FORCE (NEWTONS)
1500
1000
500
0
-500
10
15
20
25
30
Time (sec)

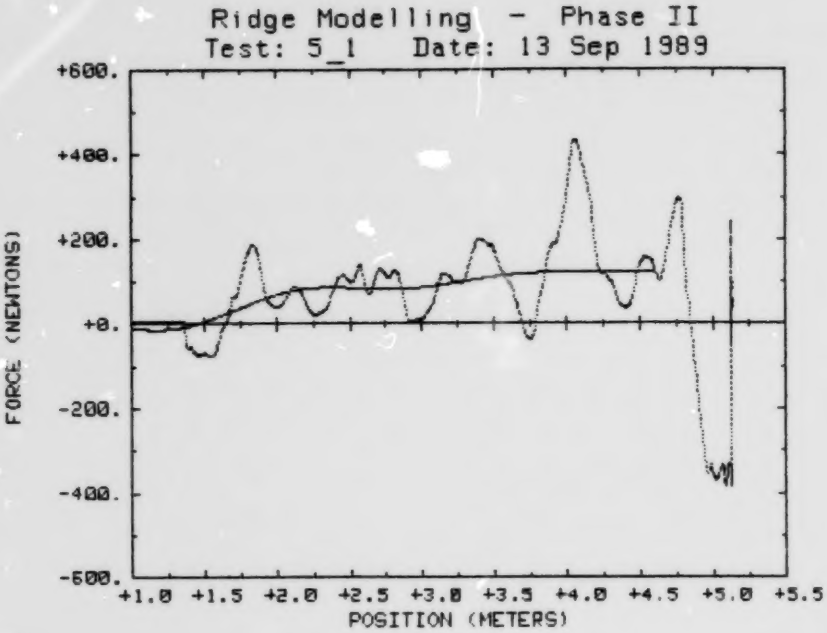

RIDGE MODELLING for 5 1
POSITION (METERS)
6
5
4
3
2
1
0
10
15
20
25
30
Time (sec)

RIDGE MODELLING
Project:3165C Test:5_1

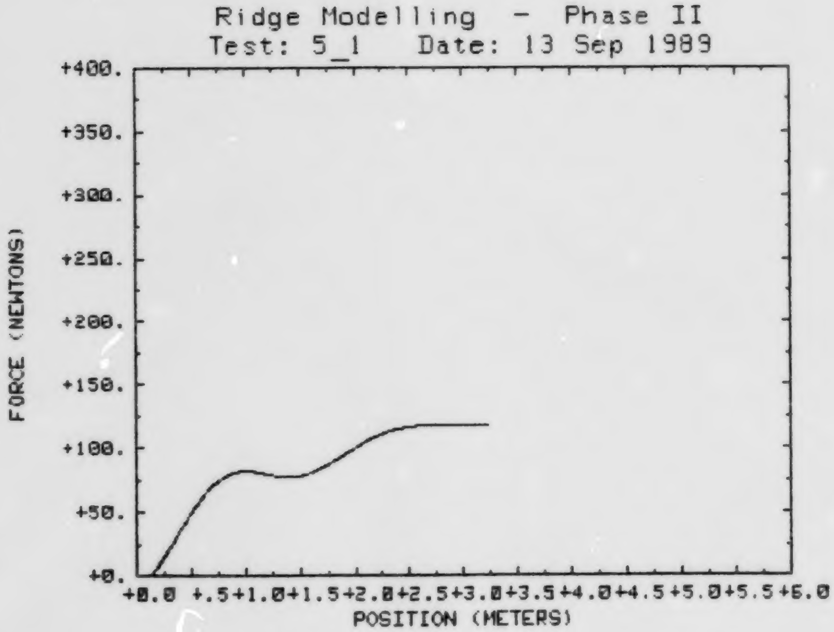


Ridge Modelling - Phase II
Test: 5_1 Date: 13 Sep 1989

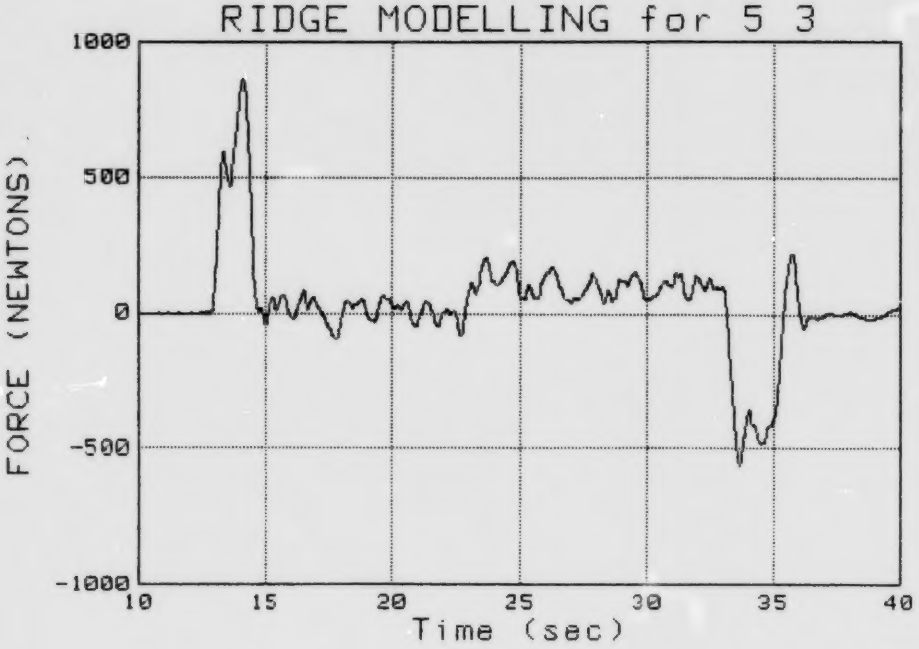


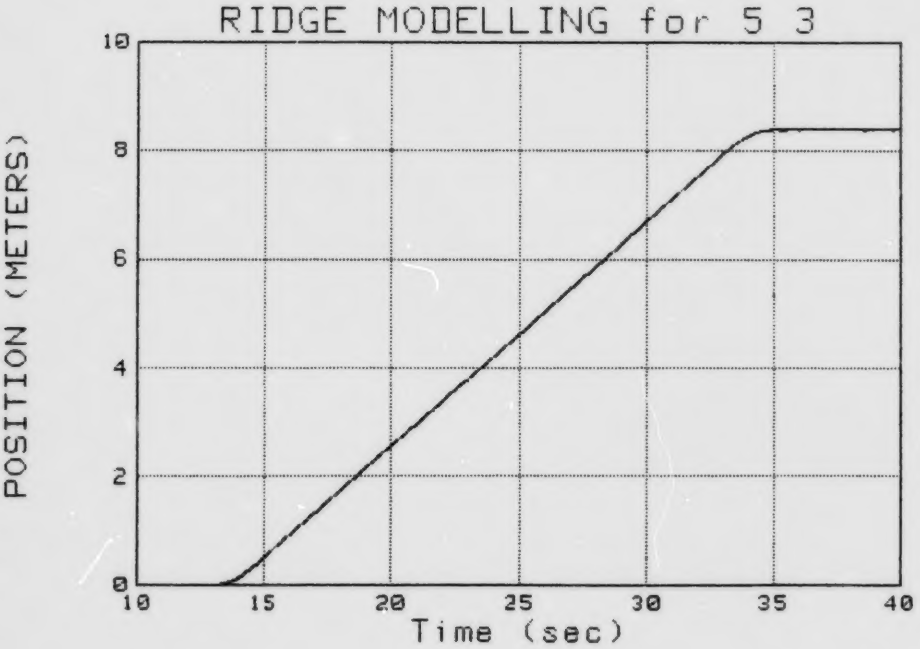


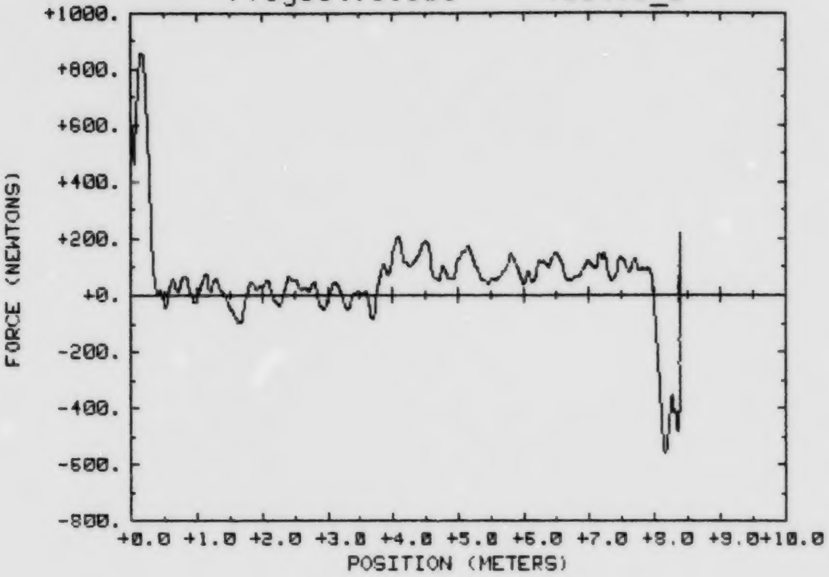
Ridge Modelling - Phase II
Test: 5_1 Date: 13 Sep 1989



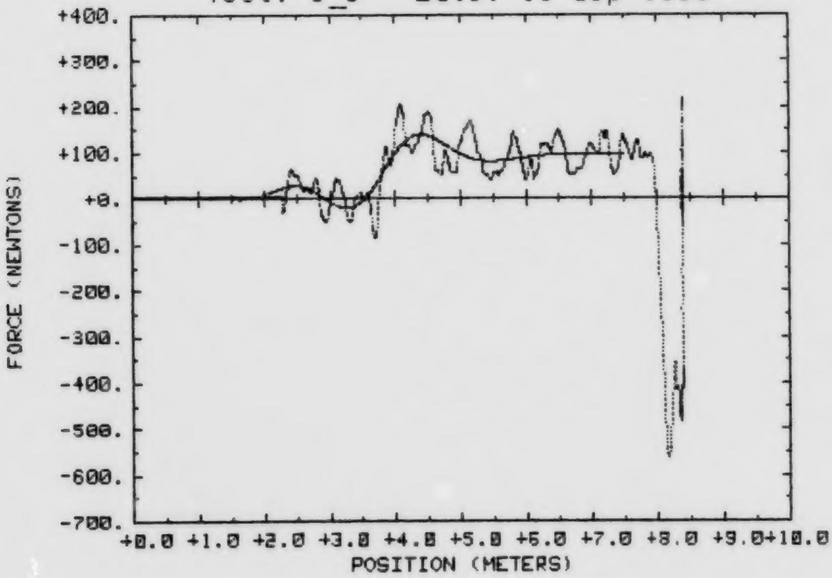
Ridge Modelling - Phase II
Test: 5_1 Date: 13 Sep 1989


RIDGE MODELLING for 5 3
FORCE (NEWTONS)
1000
500
0
-500
-1000
10
15
20
25
30
35
40
Time (sec)


RIDGE MODELLING for 5 3
POSITION (METERS)
10
8
6
4
2
0
10
15
20
25
30
35
40
Time (sec)

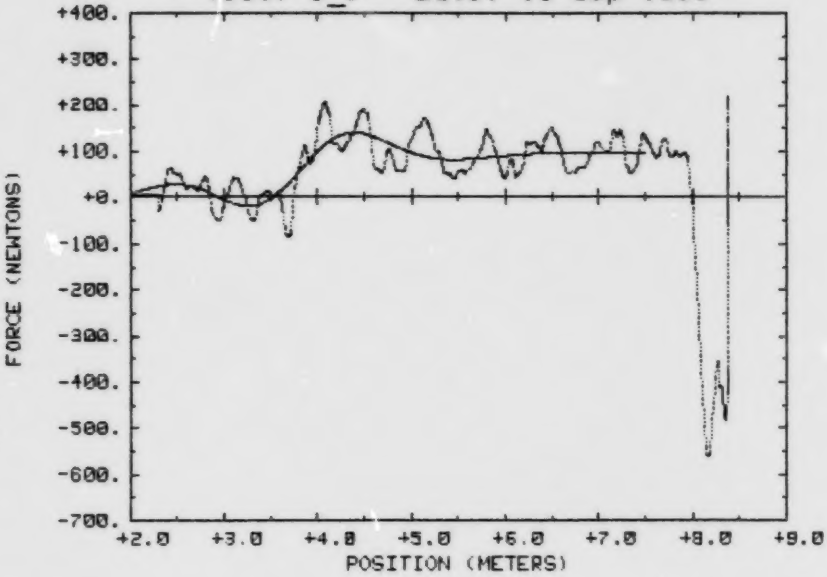


RIDGE MODELLING
Project:3165C Test:5_3

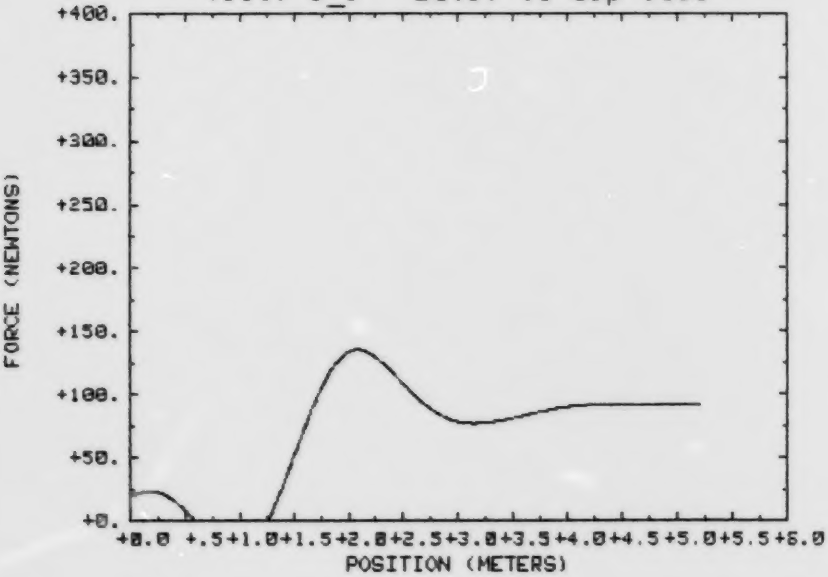


Ridge Modelling - Phase II
Test: 5_3 Date: 13 Sep 1989

Ridge Modelling - Phase II
Test: 5_3 Date: 13 Sep 1989

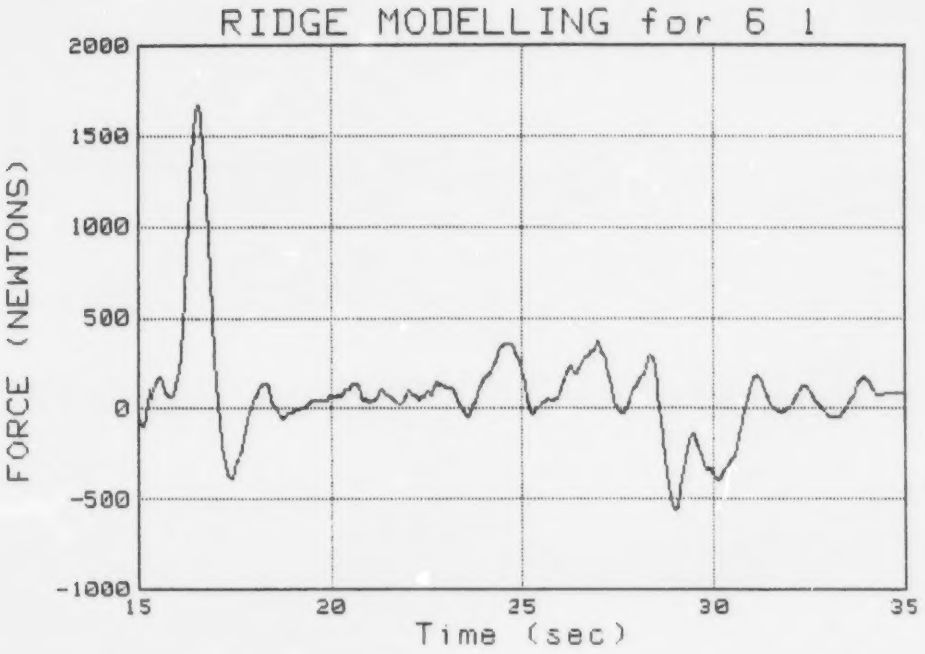


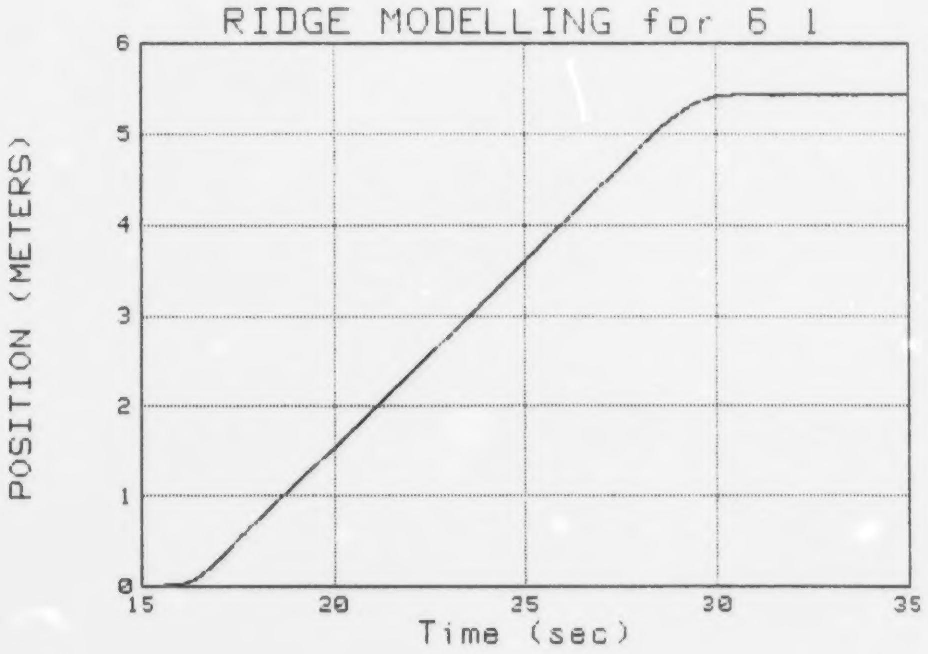
Ridge Modelling - Phase II
Test: 5_3 Date: 13 Sep 1989



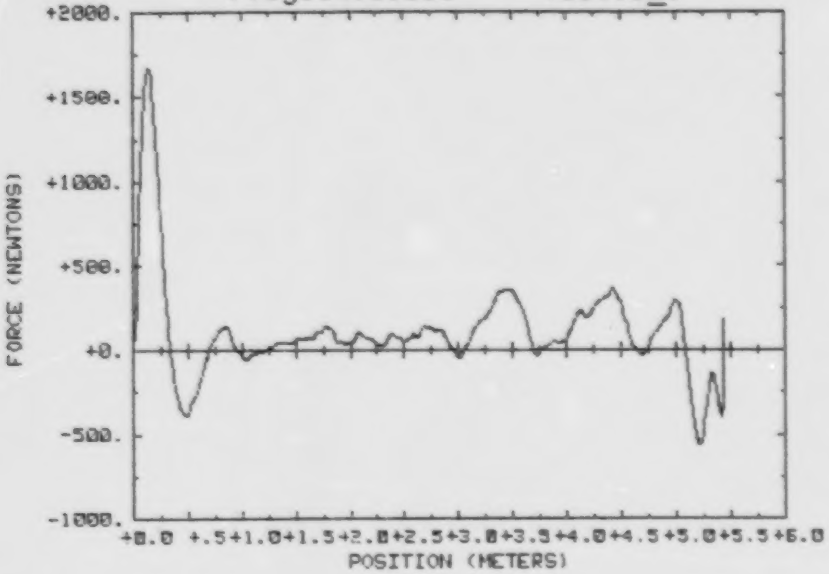
APPENDIX F

TEST DATA FOR SHEET #6

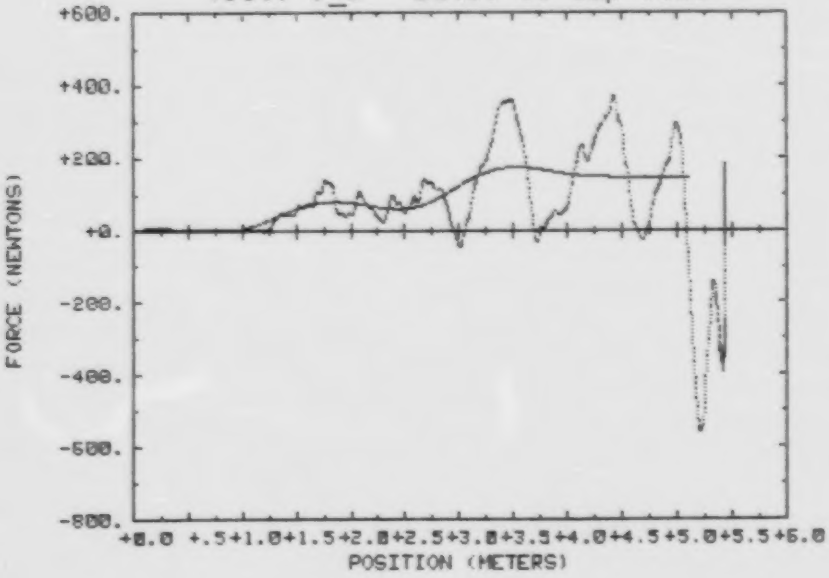

RIDGE MODELLING for 6 1
FORCE (NEWTONS)
2000
1500
1000
500
0
-500
-1000
15
20
25
30
35
Time (sec)

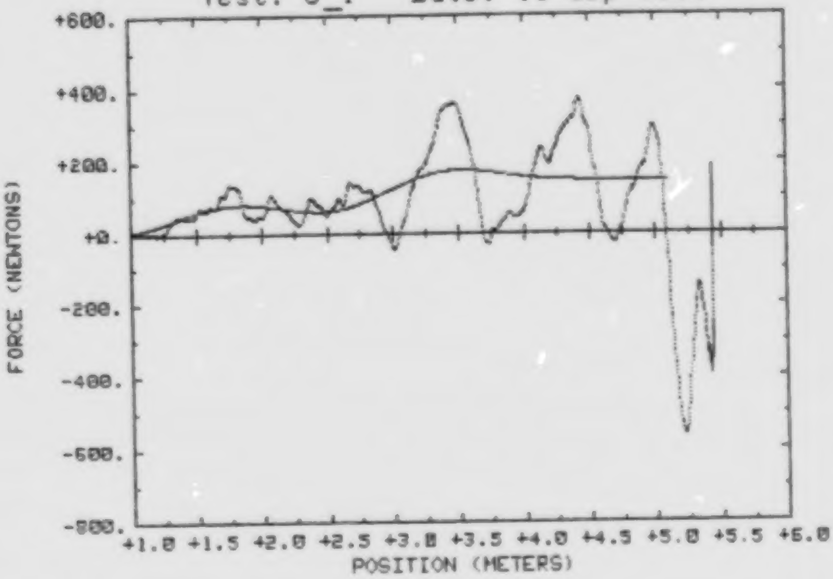

RIDGE MODELLING for 6 1
POSITION (METERS)
6
5
4
3
2
1
0
15
20
25
30
35
Time (sec)

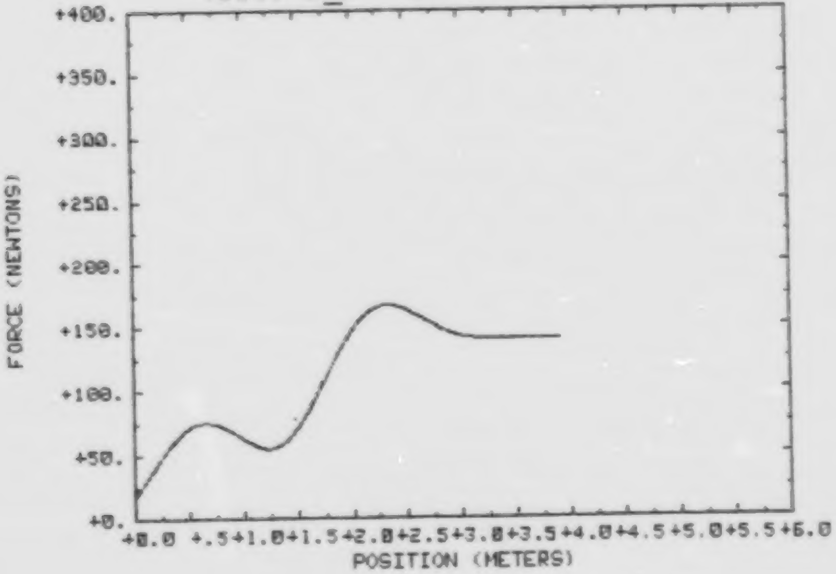
RIDGE MODELLING
Project:3165C Test:6_1

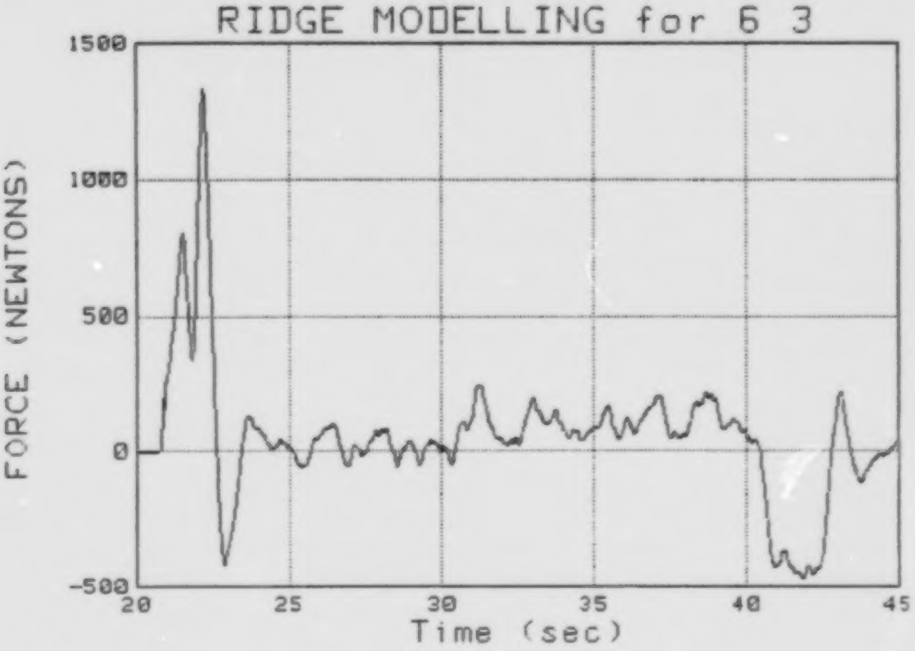


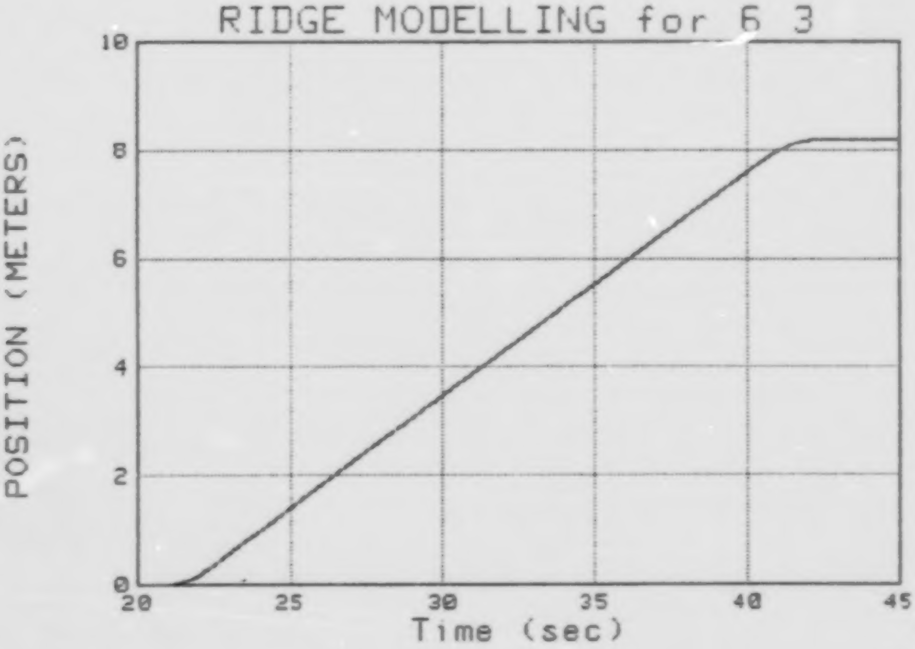
Ridge Modelling - Phase II
Test: 6_1 Date: 15 Sep 1989

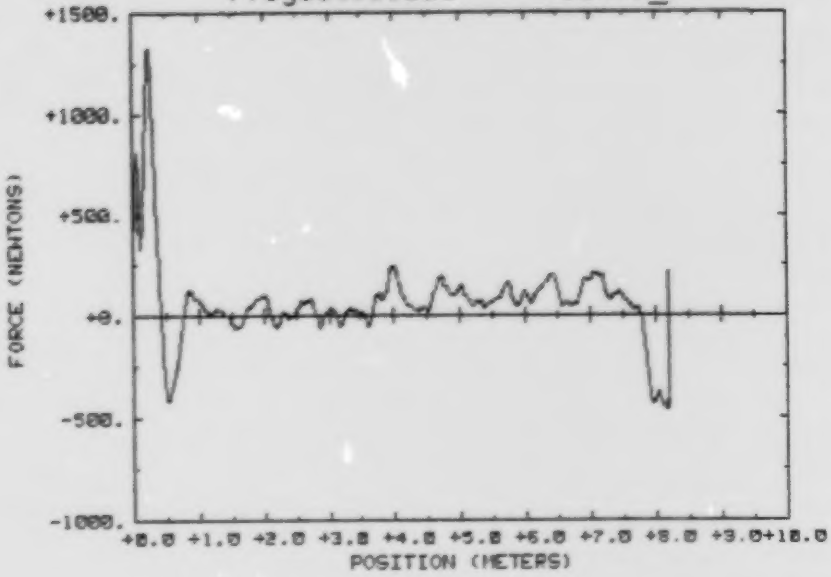



Ridge Modelling - Phase II
Test: 6_1 Date: 15 Sep 1989

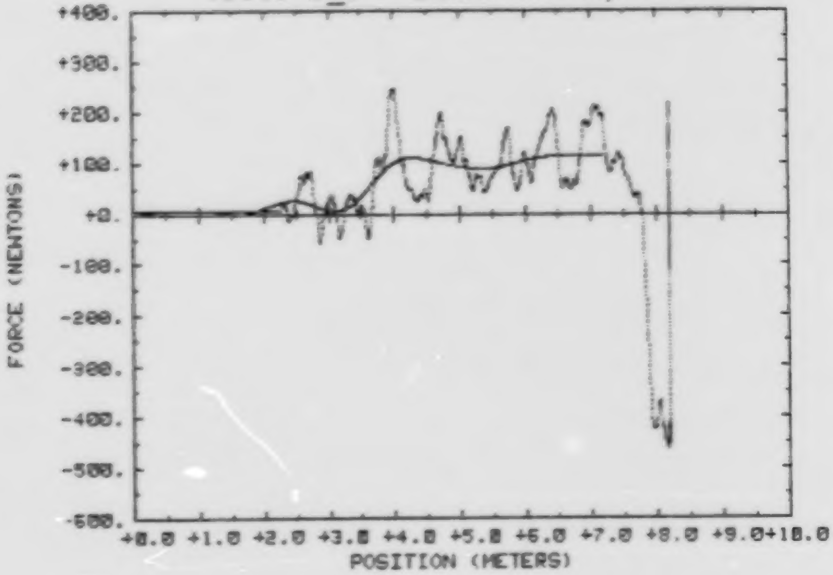

Ridge Modelling - Phase II
Test: 6_1 Date: 15 Sep 1989


RIDGE MODELLING for 6 3


RIDGE MODELLING for 6 3

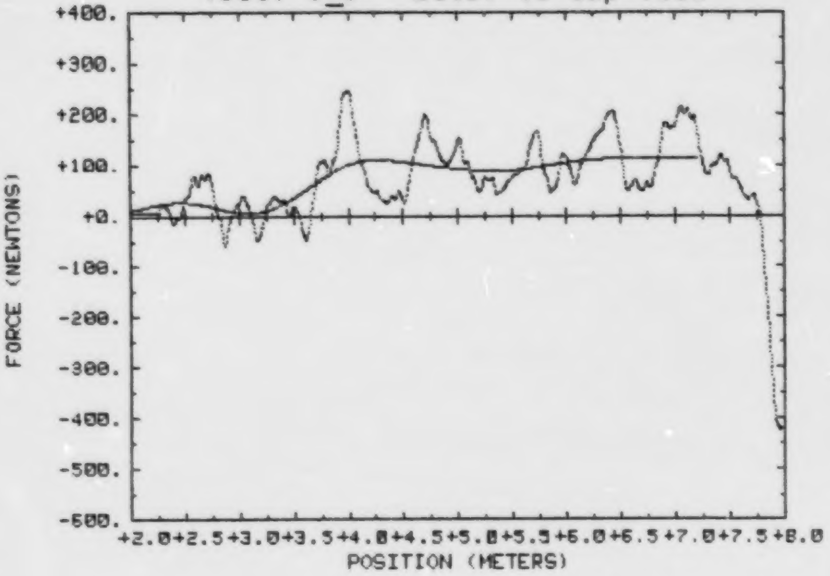


RIDGE MODELLING
Project:3165C Test:6_3

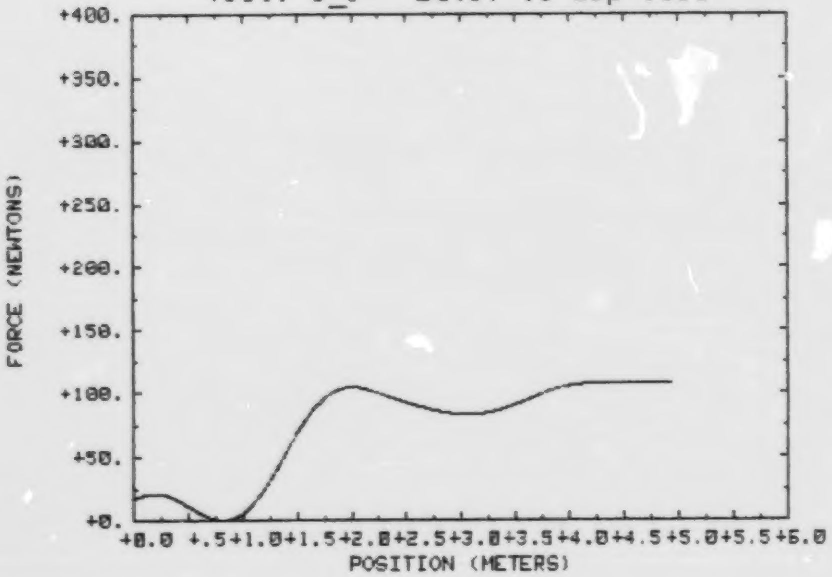


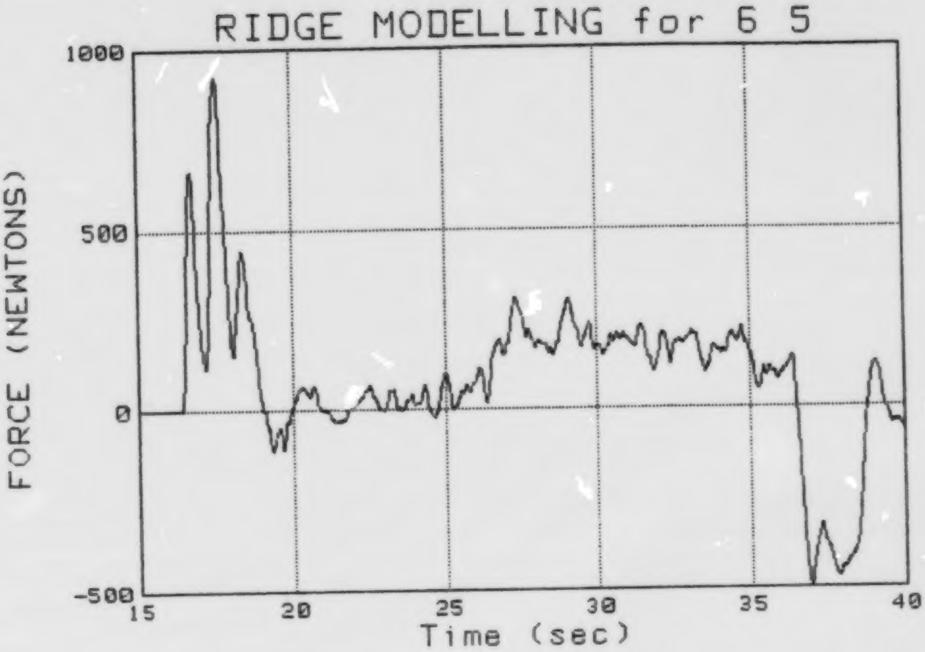
Ridge Modelling - Phase II
Test: 6_3 Date: 15 Sep 1989

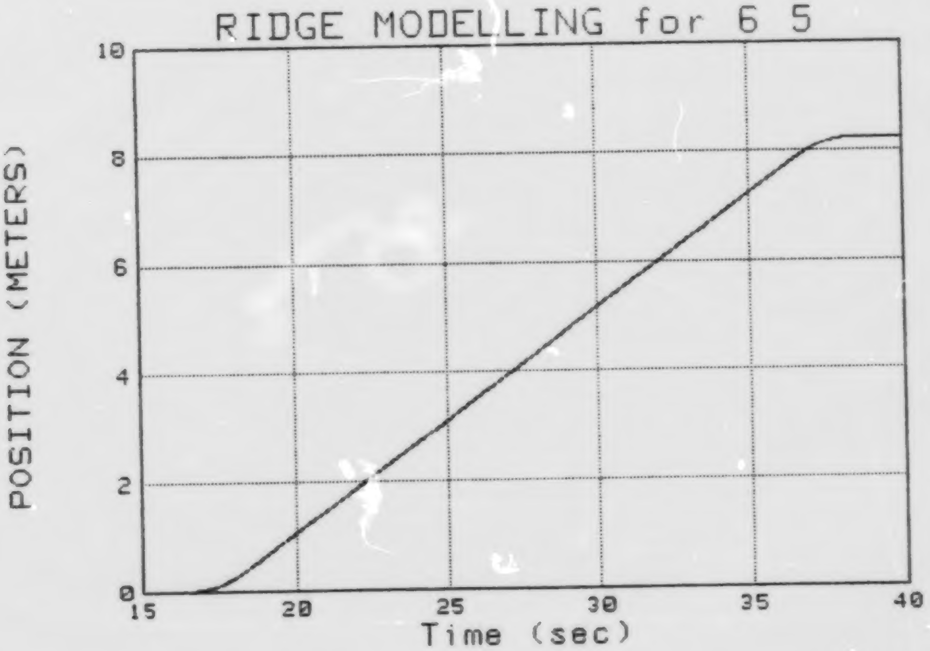
Ridge Modelling - Phase II
Test: 6_3 Date: 15 Sep 1989

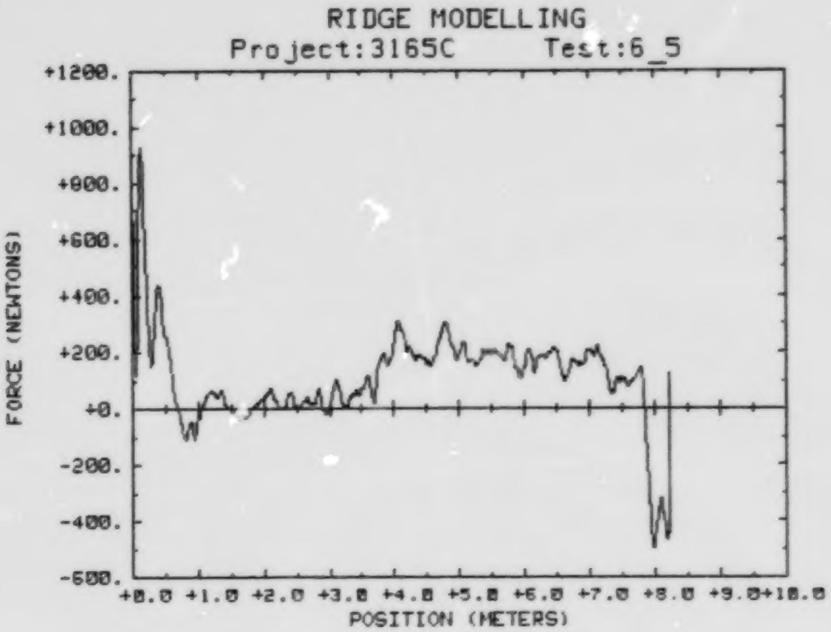


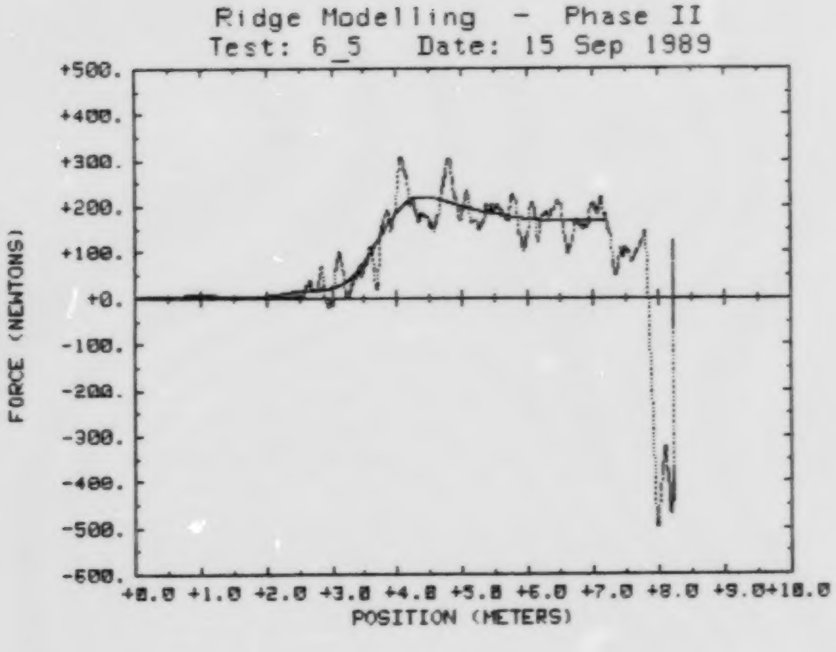
Ridge Modelling - Phase II
Test: 6_3 Date: 15 Sep 1989

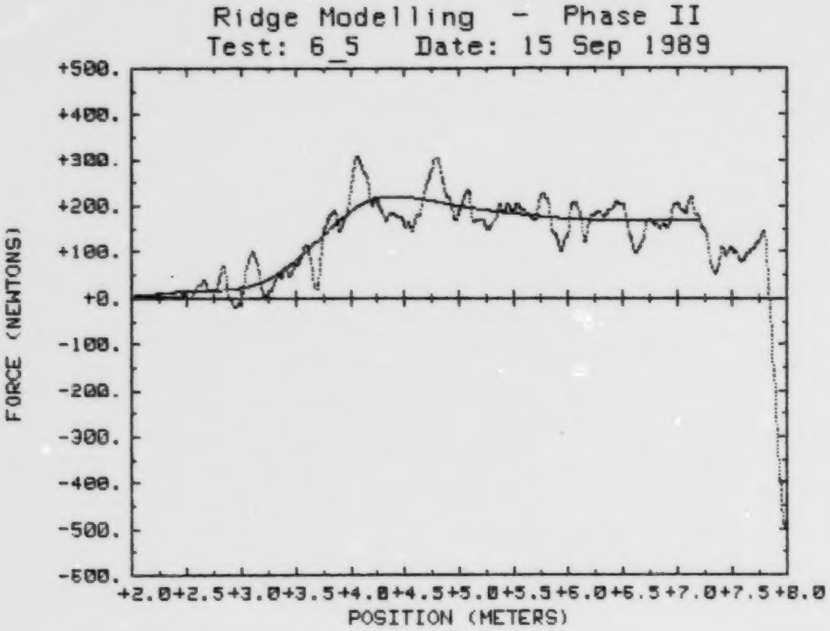


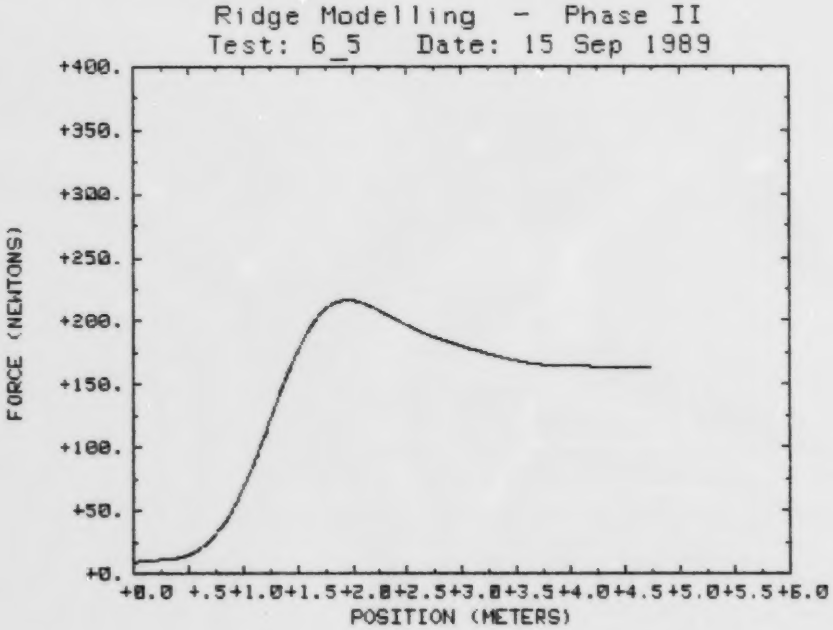

RIDGE MODELLING for 6 5


RIDGE MODELLING for 6 5


RIDGE MODELLING
Project:3165C Test:6_5
FORCE (NEWTONS)
+1200.
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

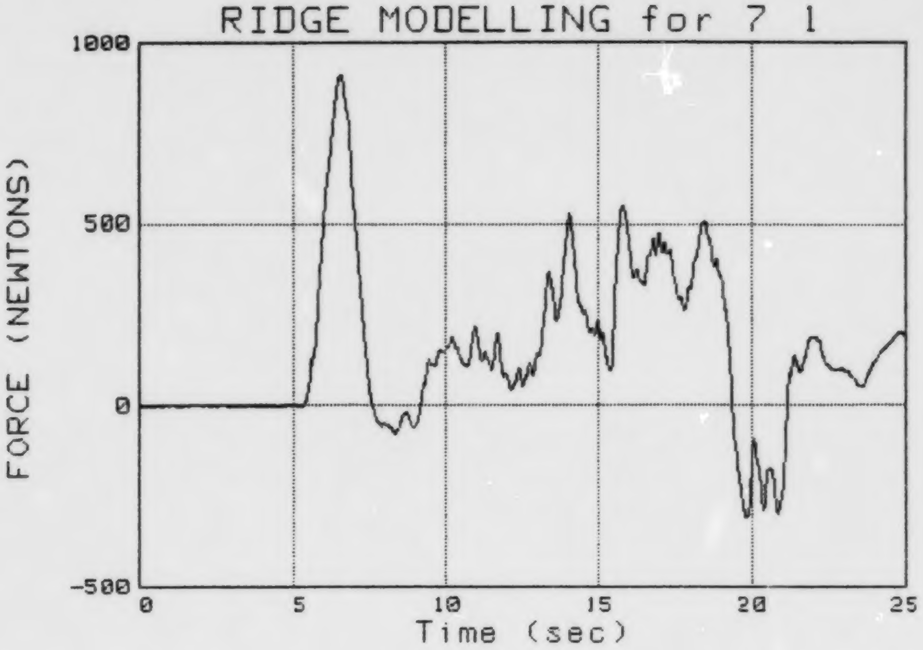

Ridge Modelling - Phase II
Test: 6_5 Date: 15 Sep 1989
FORCE (NEWTONS)
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 6_5 Date: 15 Sep 1989

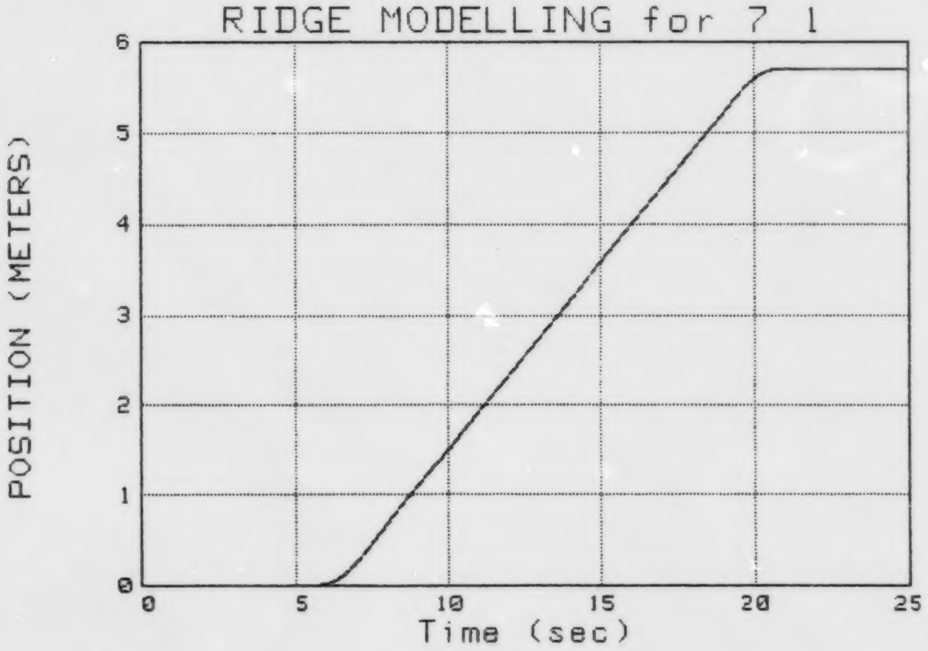

Ridge Modelling - Phase II
Test: 6_5 Date: 15 Sep 1989

APPENDIX G

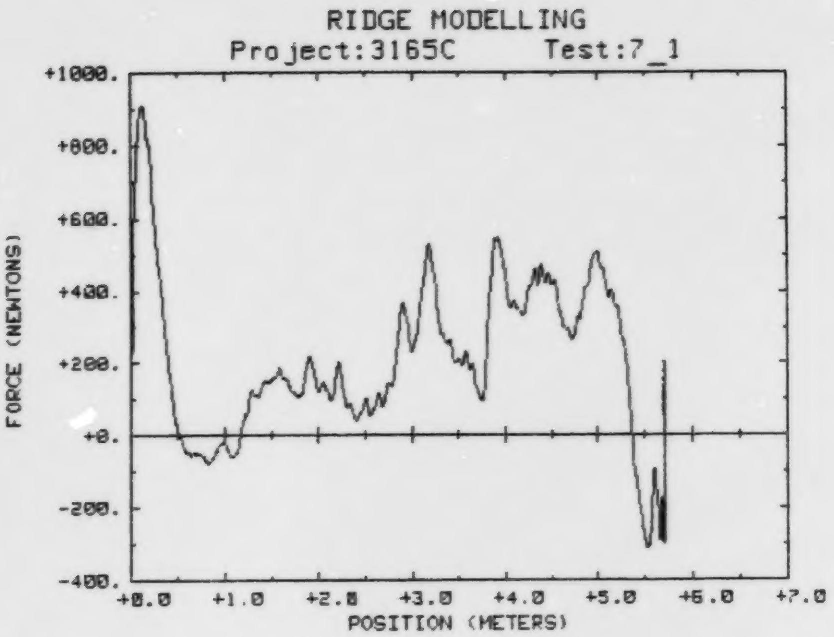
TEST DATA FOR SHEET #7

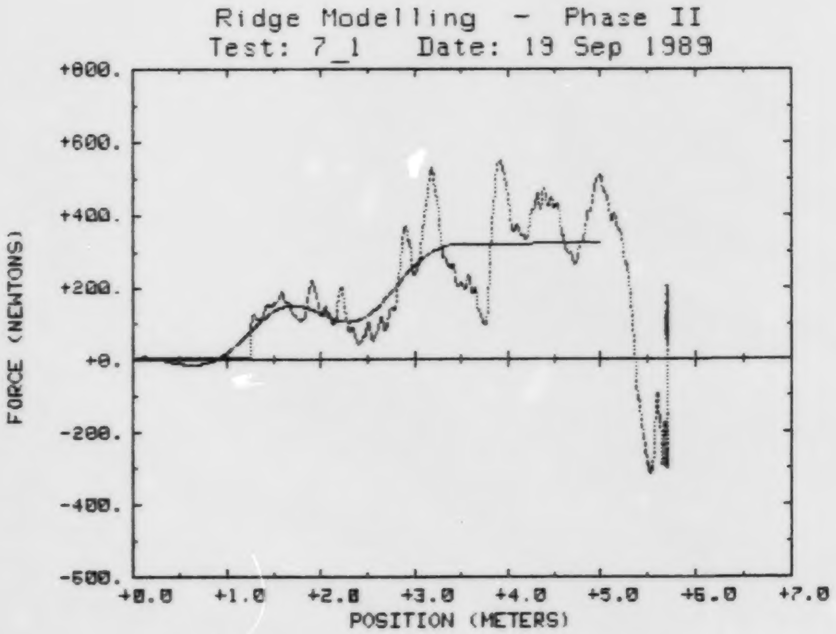


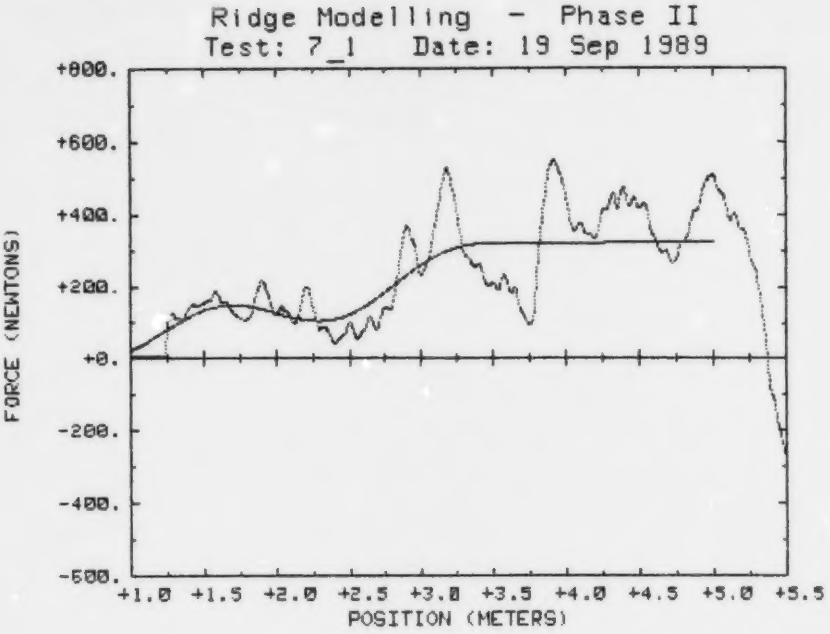
RIDGE MODELLING for 7 1

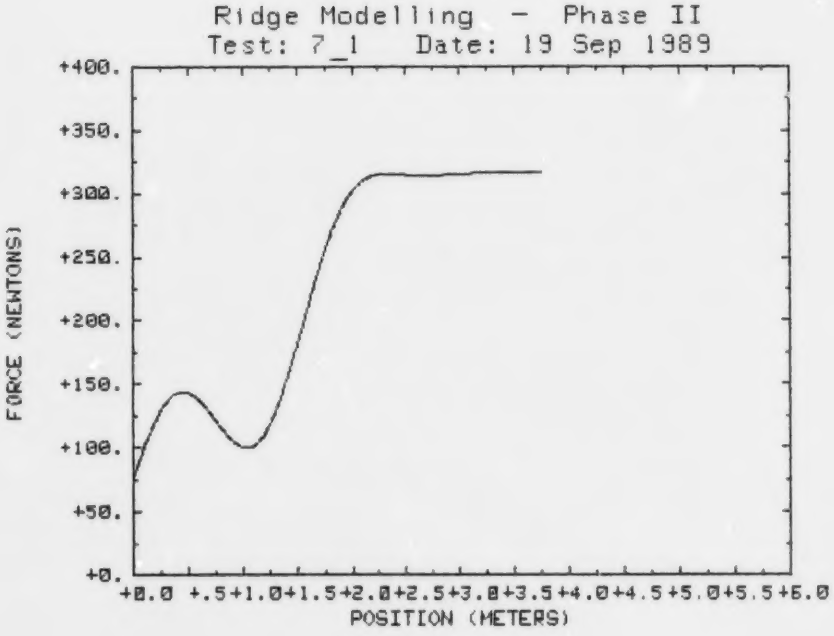


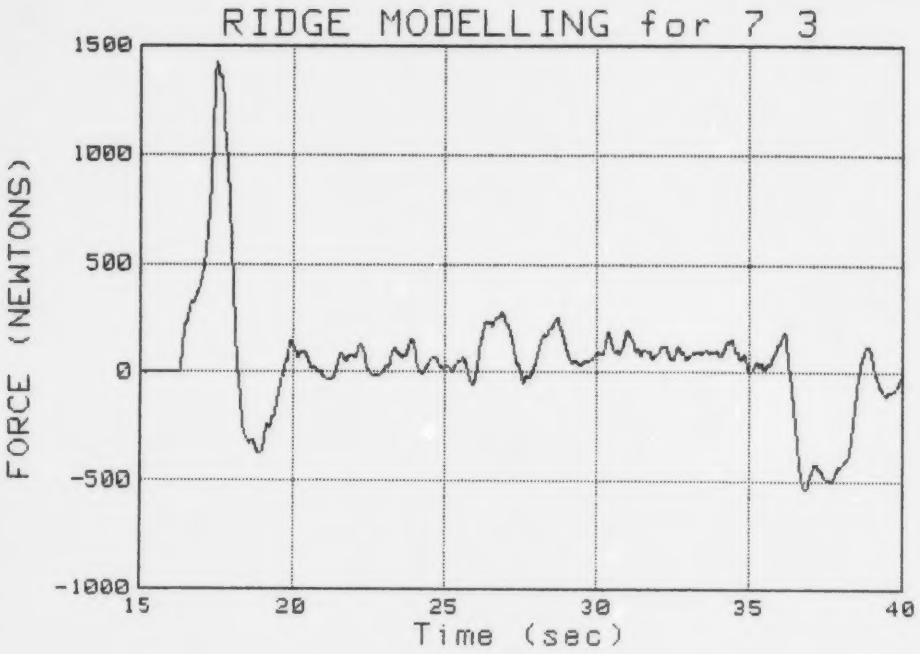
RIDGE MODELLING for 7 1

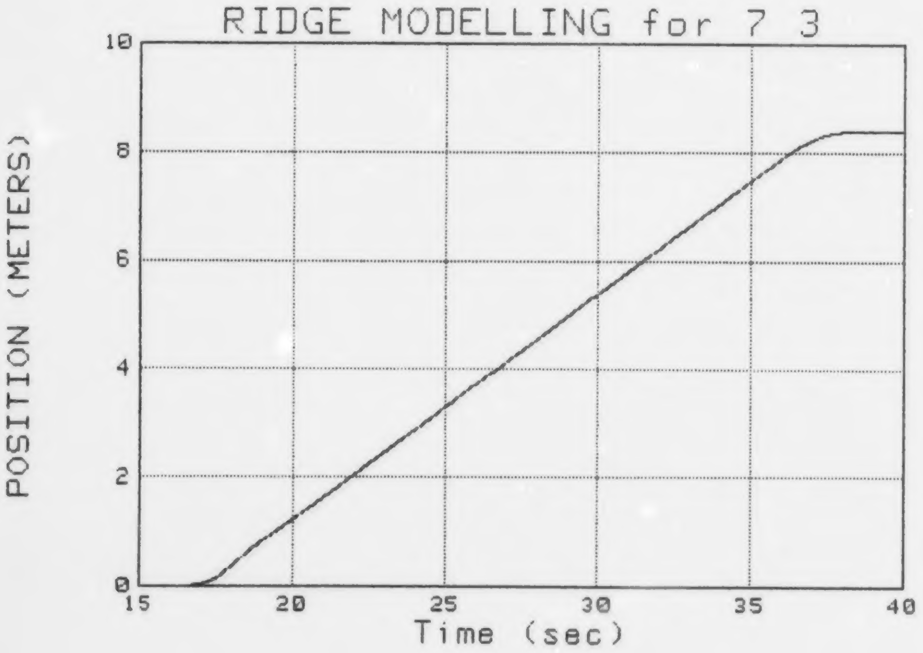

RIDGE MODELLING
Project:3165C Test:7_1
FORCE (NEWTONS)
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
POSITION (METERS)

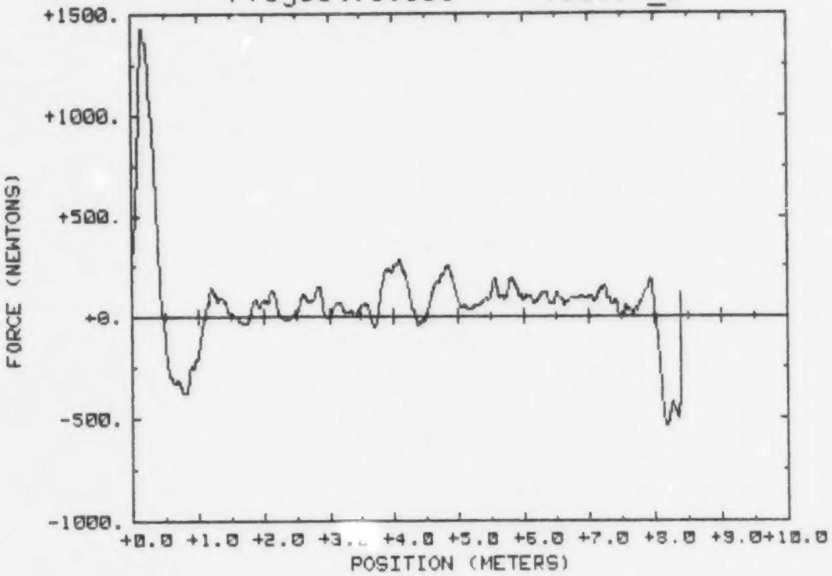

Ridge Modelling - Phase II
Test: 7_1 Date: 19 Sep 1989
FORCE (NEWTONS)
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: 7_1 Date: 19 Sep 1989
FORCE (NEWTONS)
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
POSITION (METERS)

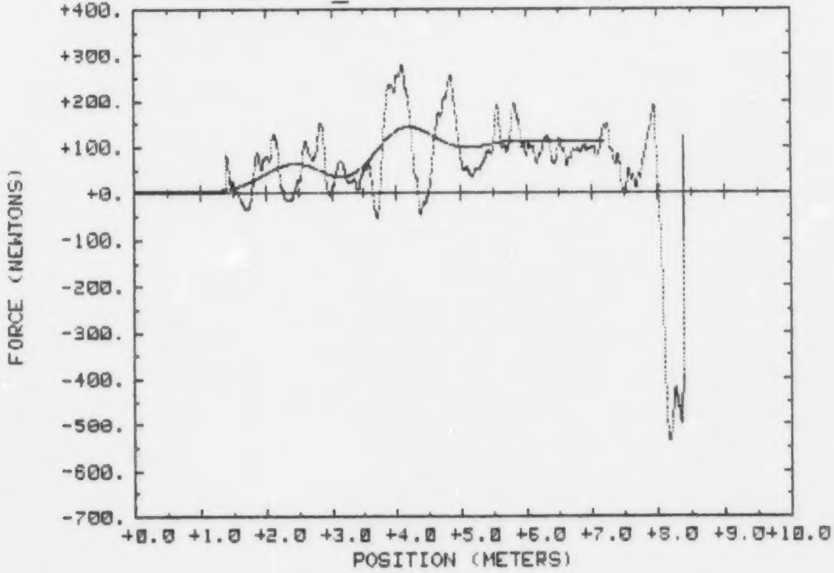

Ridge Modelling - Phase II
Test: 7_1 Date: 19 Sep 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)


RIDGE MODELLING for 7 3
FORCE (NEWTONS)
1500
1000
500
0
-500
-1000
15
20
25
30
35
40
Time (sec)

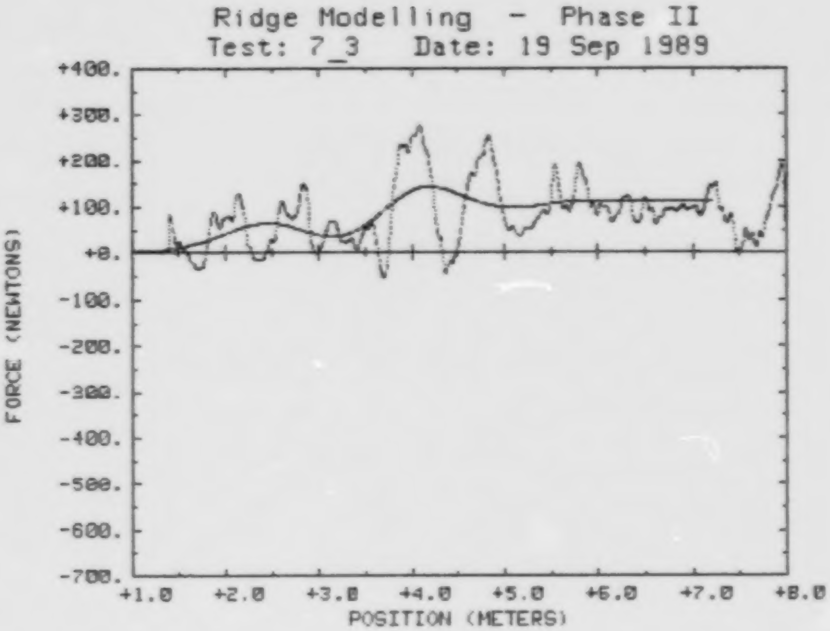

RIDGE MODELLING for 7 3
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
Time (sec)



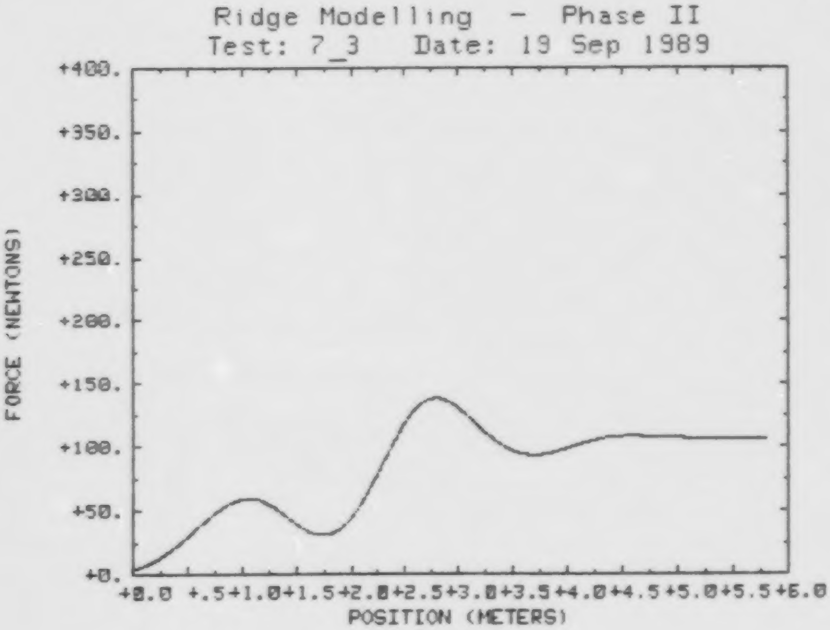
RIDGE MODELLING
Project:3165C Test:7_3



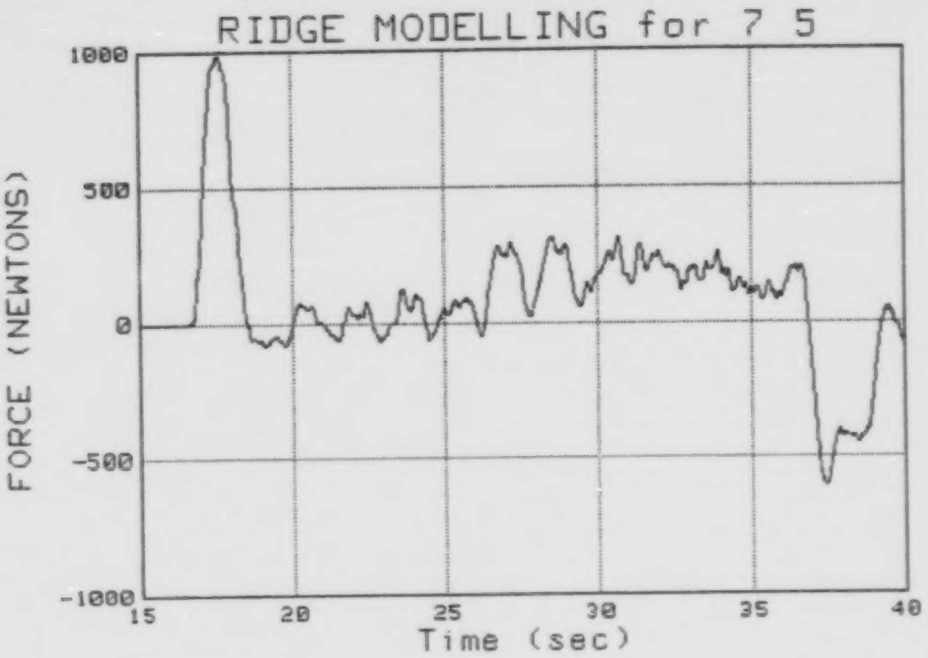
Ridge Modelling – Phase II
Test: 7_3 Date: 19 Sep 1989

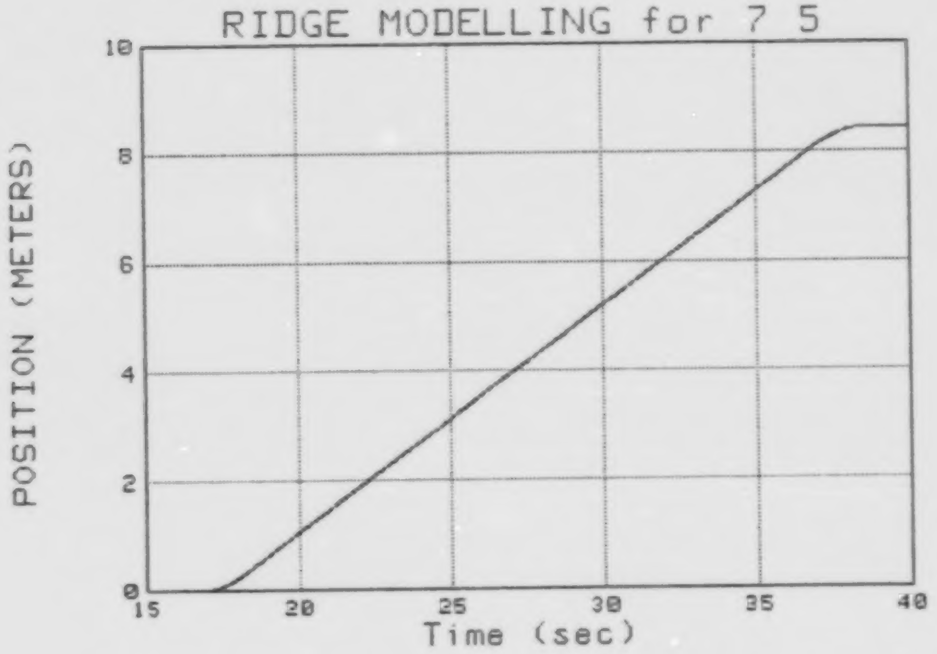


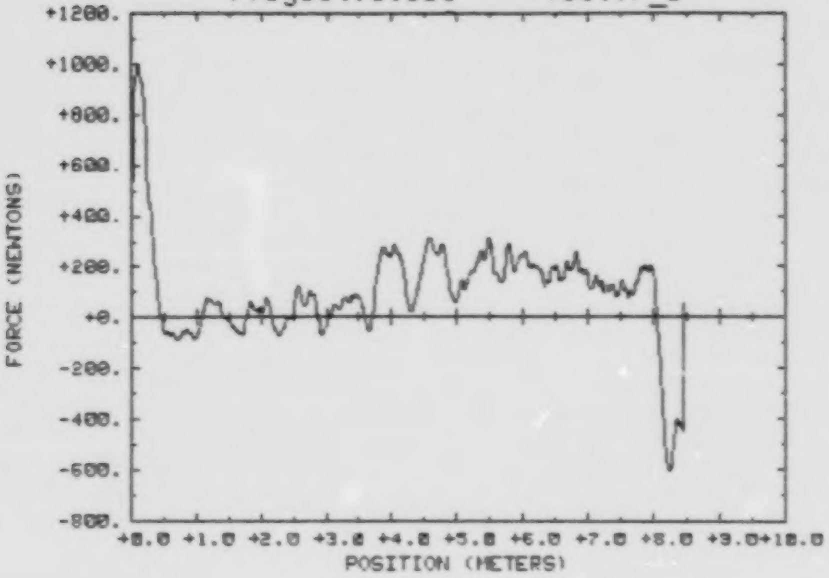
Ridge Modelling - Phase II
Test: 7_3 Date: 19 Sep 1989



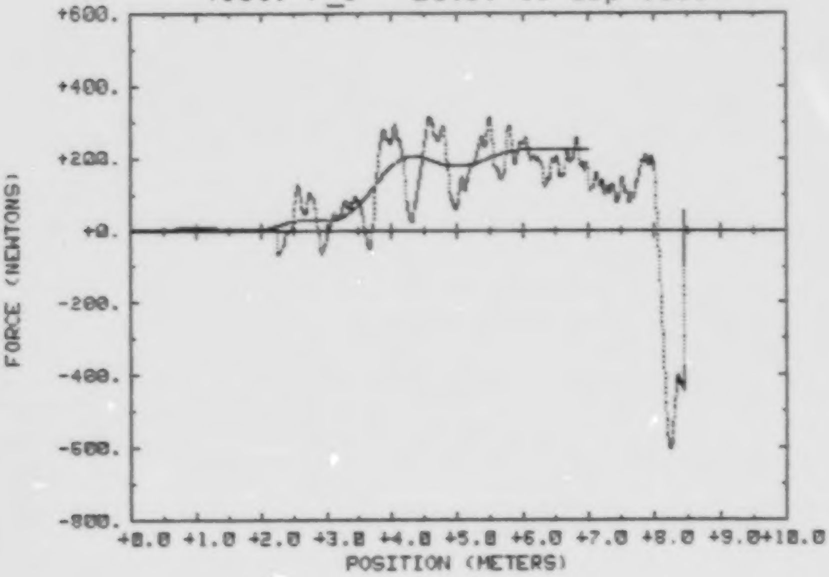
Ridge Modelling - Phase II
Test: 7_3 Date: 19 Sep 1989


RIDGE MODELLING for 7 5


RIDGE MODELLING for 7 5

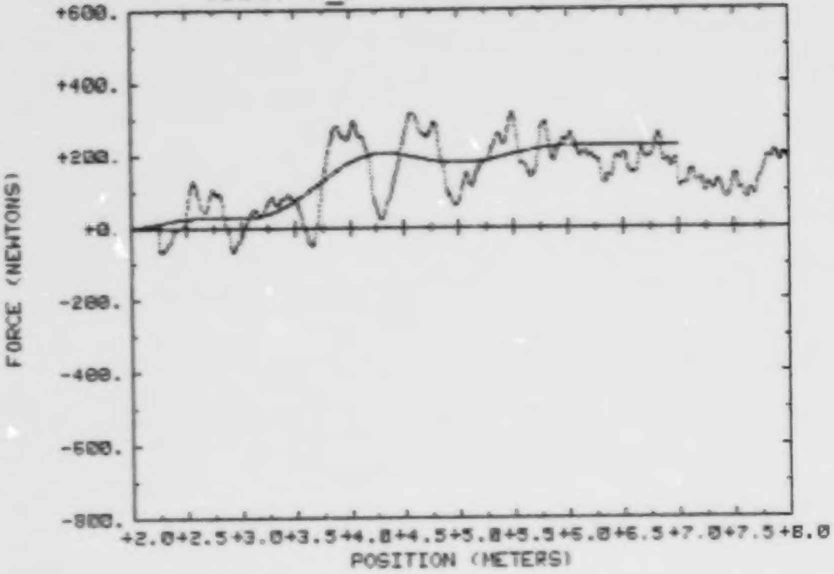


RIDGE MODELLING
Project:3165C Test:7_5

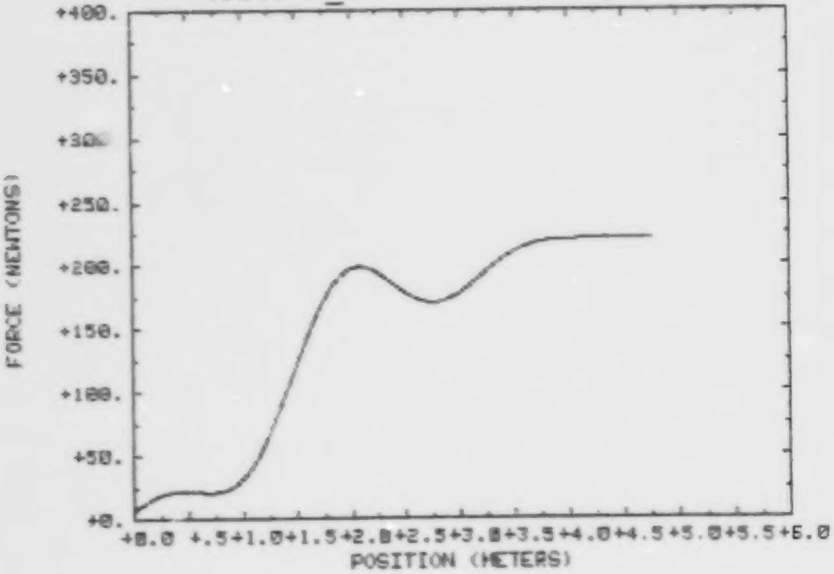


Ridge Modelling - Phase II
Test: 7_5 Date: 19 Sep 1989

Ridge Modelling - Phase II
Test: 7_5 Date: 19 Sep 1989

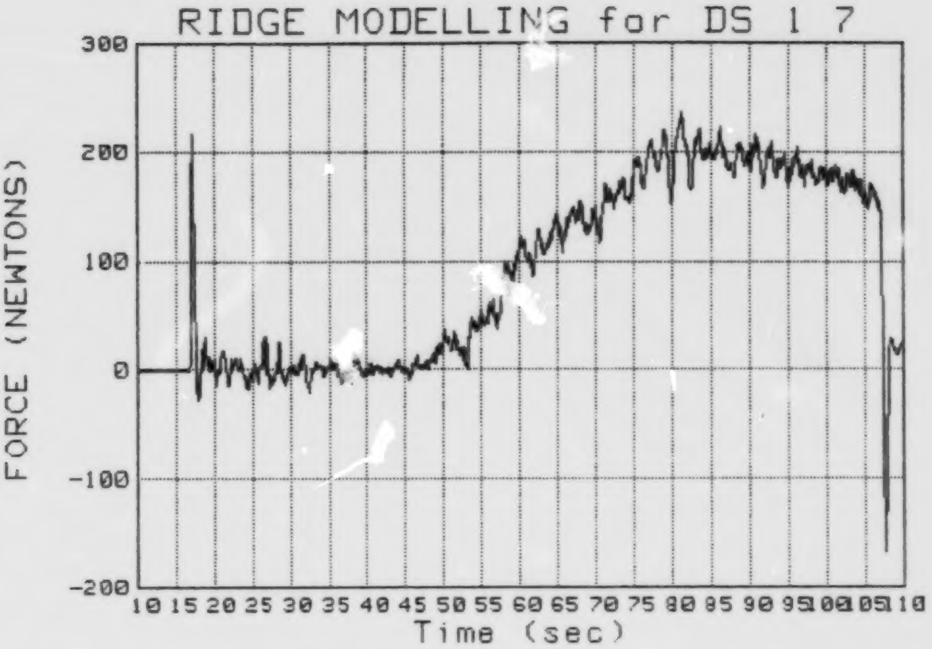


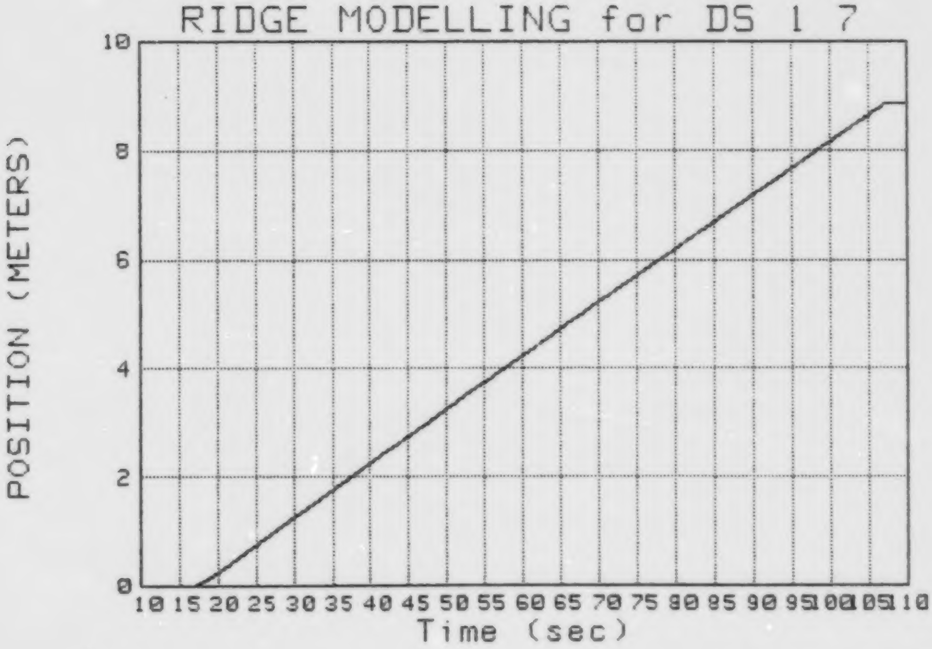
Ridge Modelling - Phase II
Test: 7_5 Date: 19 Sep 1989

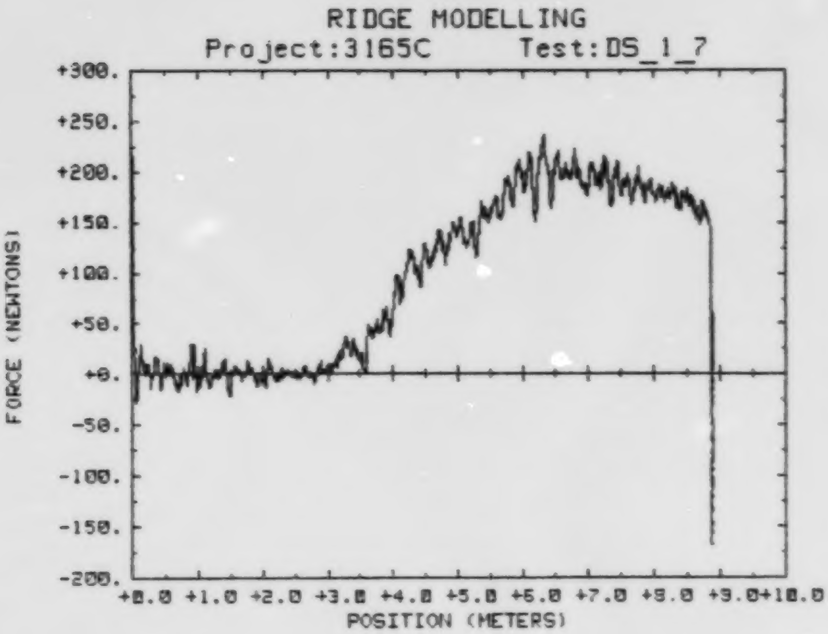


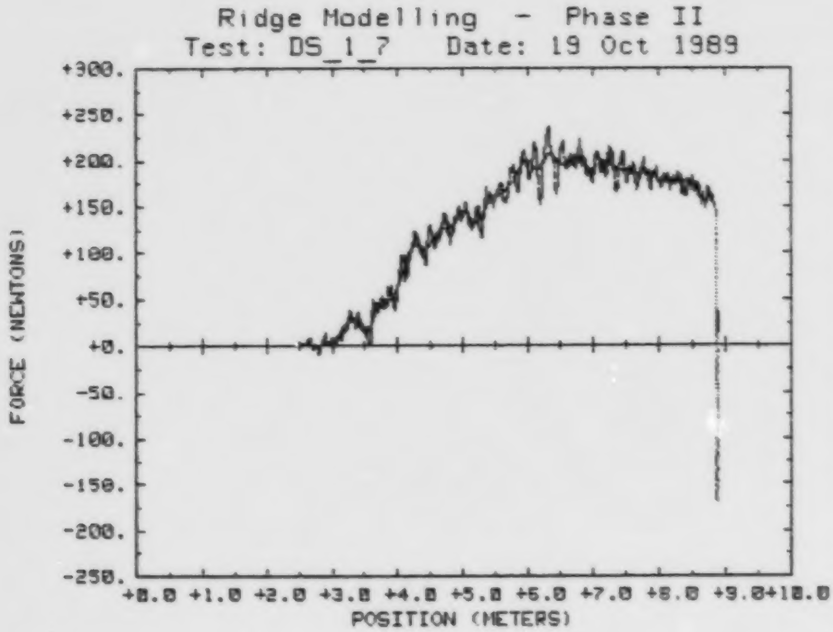
APPENDIX H

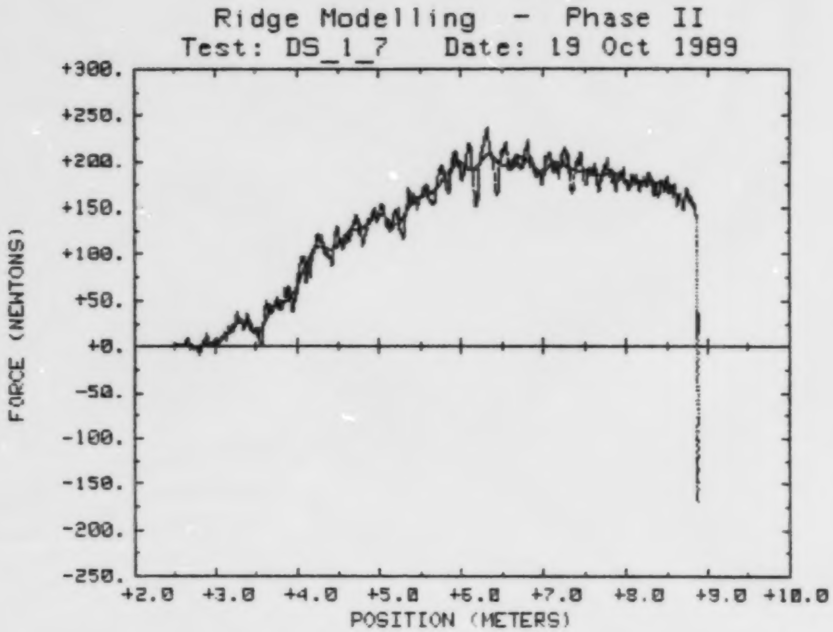
TEST DATA FOR SHEET #DS1

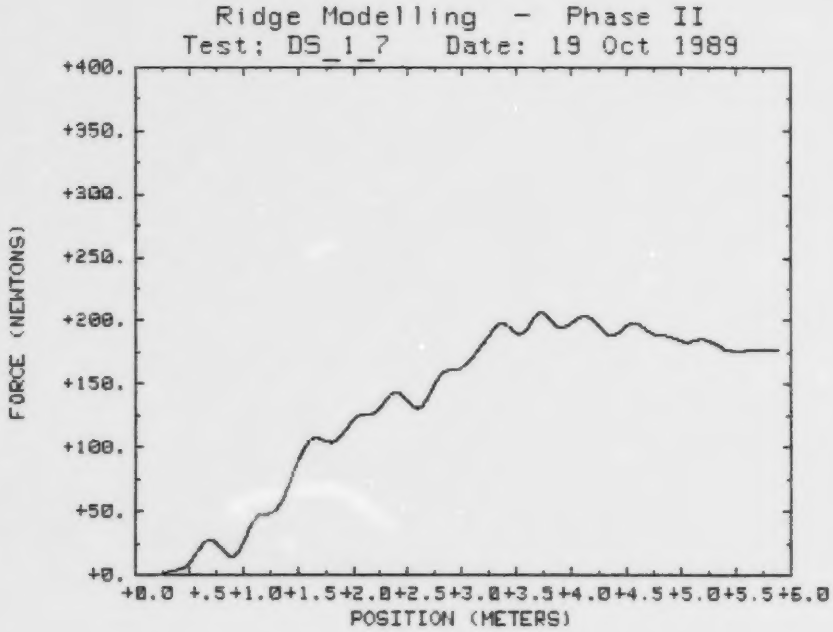

RIDGE MODELLING for DS 1 7

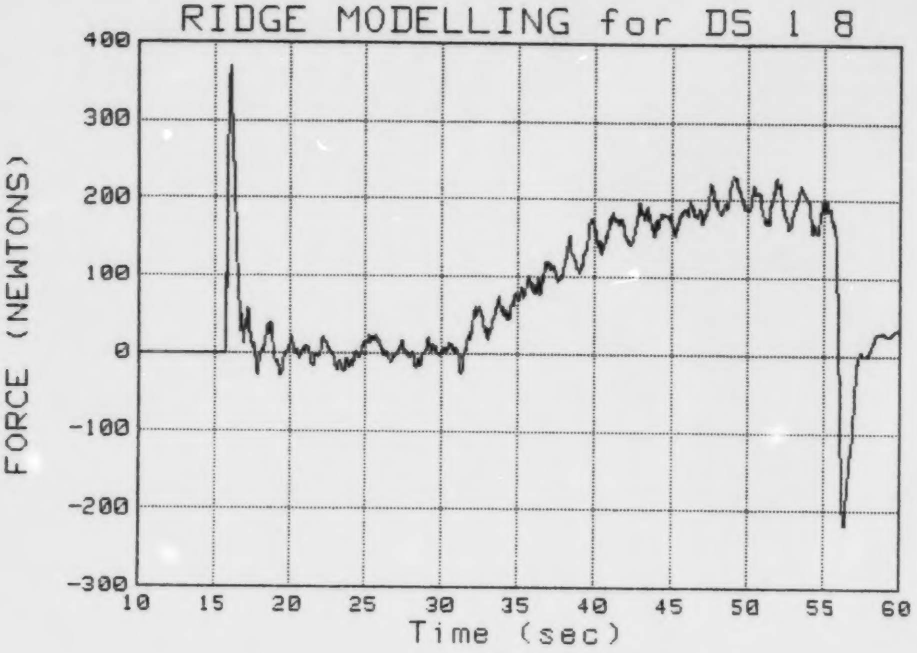

RIDGE MODELLING for DS 1 7


RIDGE MODELLING
Project:3165C Test:DS_1_7
FORCE (NEWTONS)
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

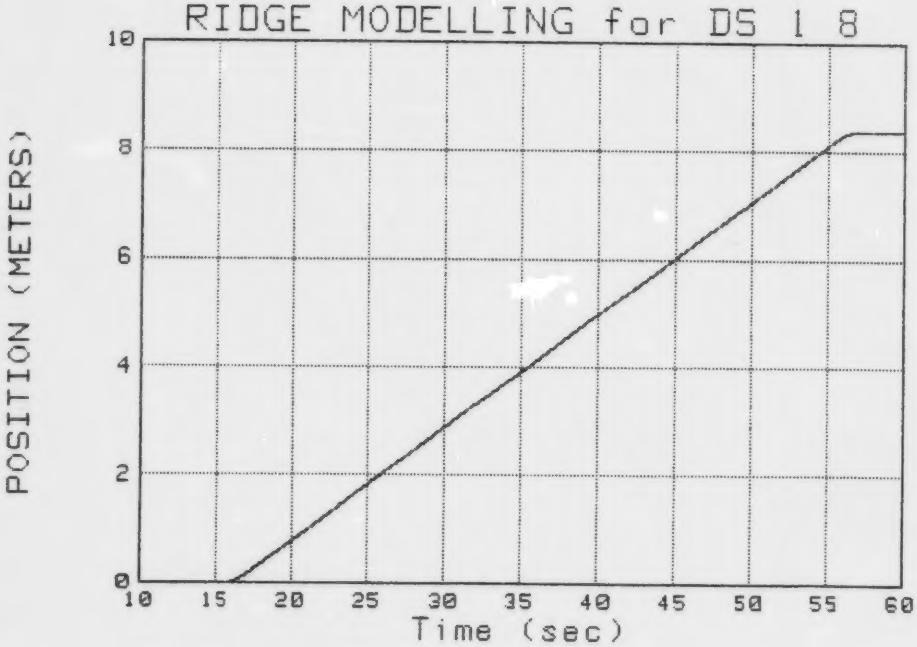

Ridge Modelling - Phase II
Test: DS_1_7 Date: 19 Oct 1989
FORCE (NEWTONS)
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS_1_7 Date: 19 Oct 1989
FORCE (NEWTONS)
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

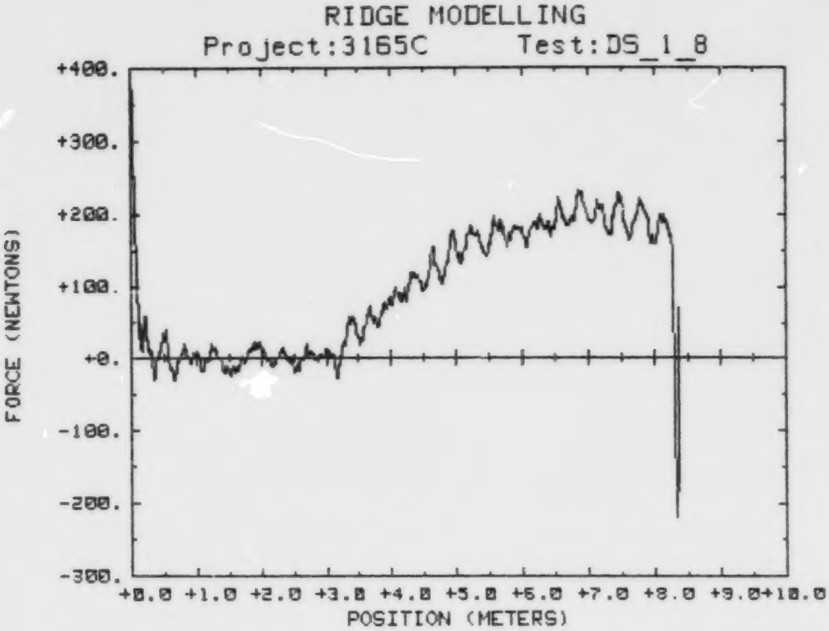

Ridge Modelling - Phase II
Test; DS_1_7 Date: 19 Oct 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)



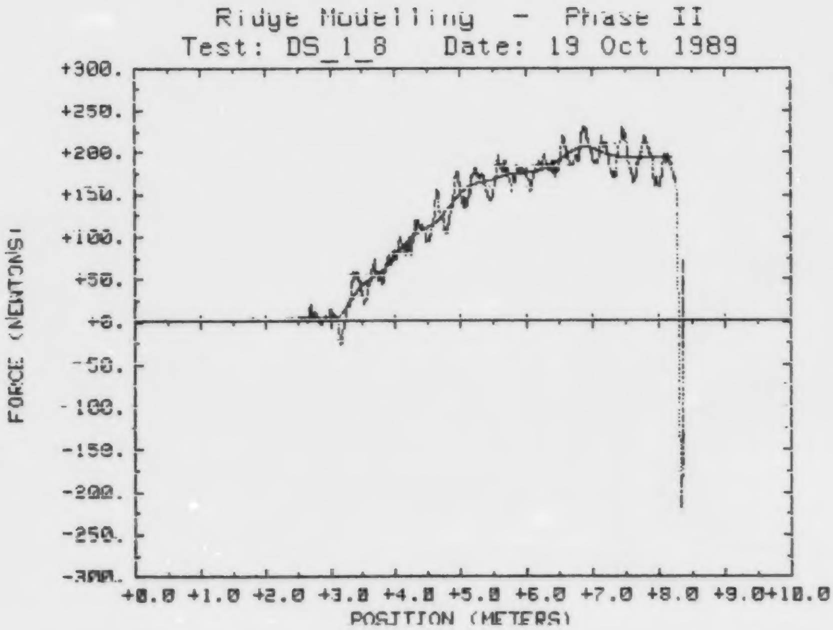
RIDGE MODELLING for DS 1 8
FORCE (NEWTONS)
400
300
200
100
0
-100
-200
-300
10
15
20
25
30
35
40
45
50
55
60
Time (sec)



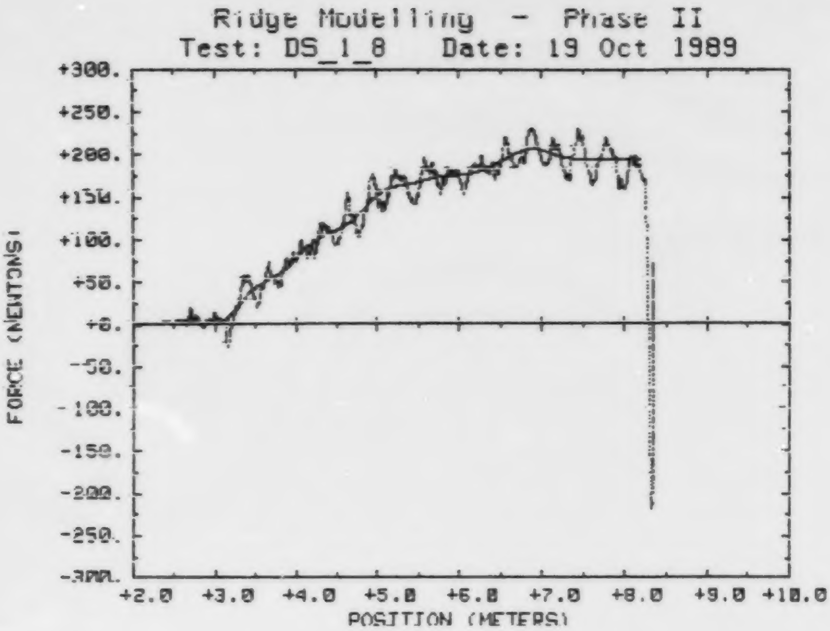
RIDGE MODELLING for DS 1 8
POSITION (METERS)
10
8
6
4
2
0
10
15
20
25
30
35
40
45
50
55
60
Time (sec)



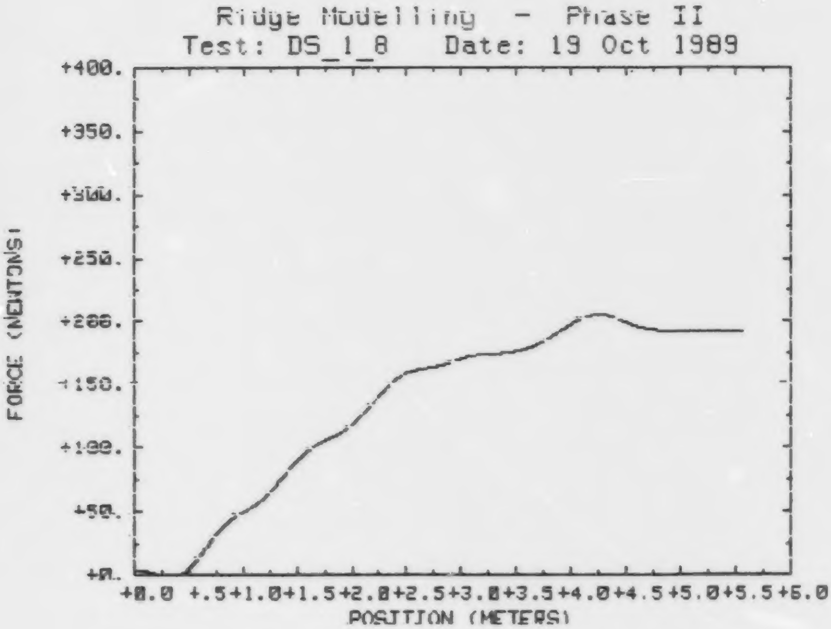
RIDGE MODELLING
Project:3165C Test:DS_1_8



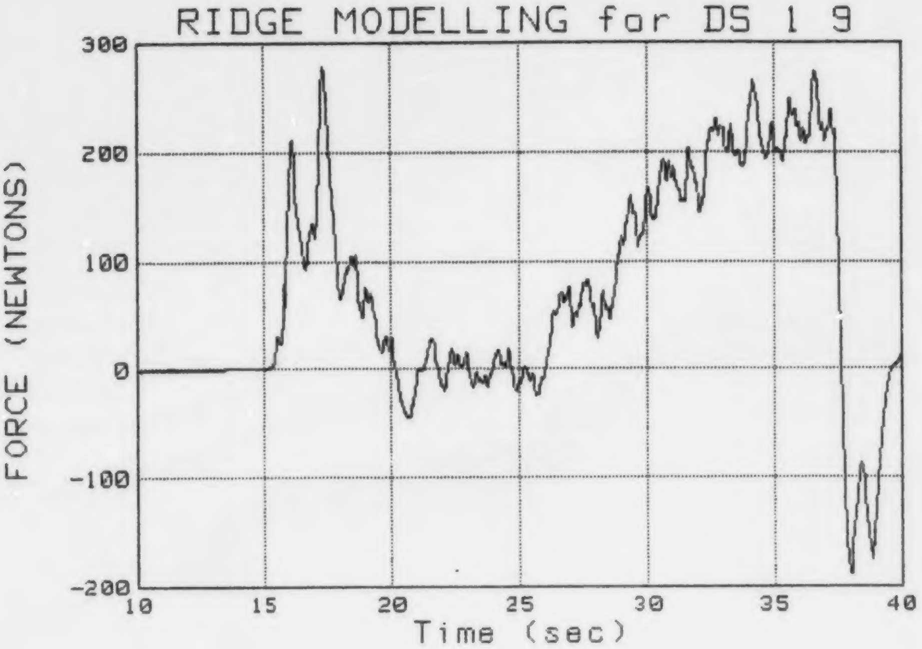
Ridge Modelling - Phase II
Test: DS_1_8 Date: 19 Oct 1989

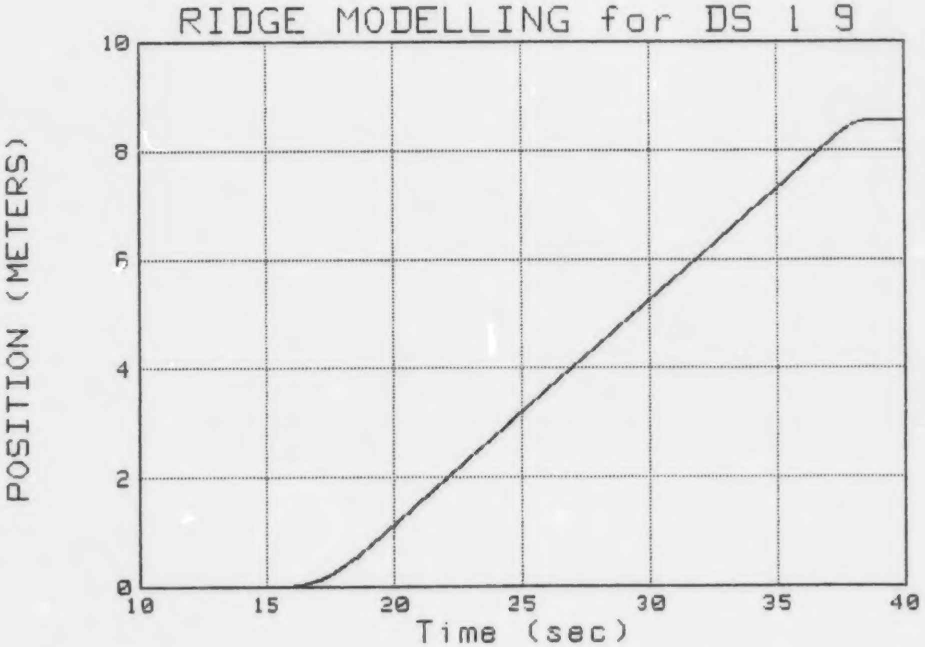


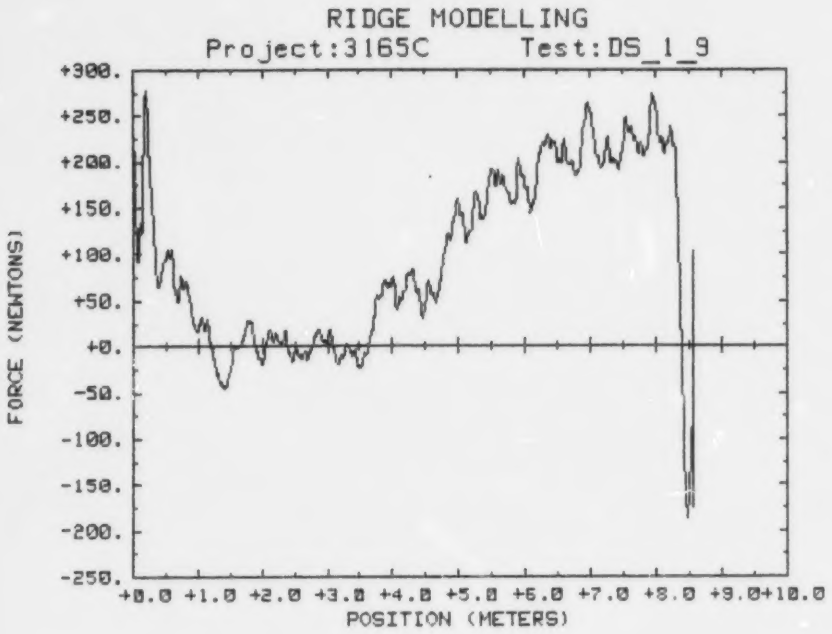
Ridge Modelling - Phase II
Test: DS_1_8 Date: 19 Oct 1989

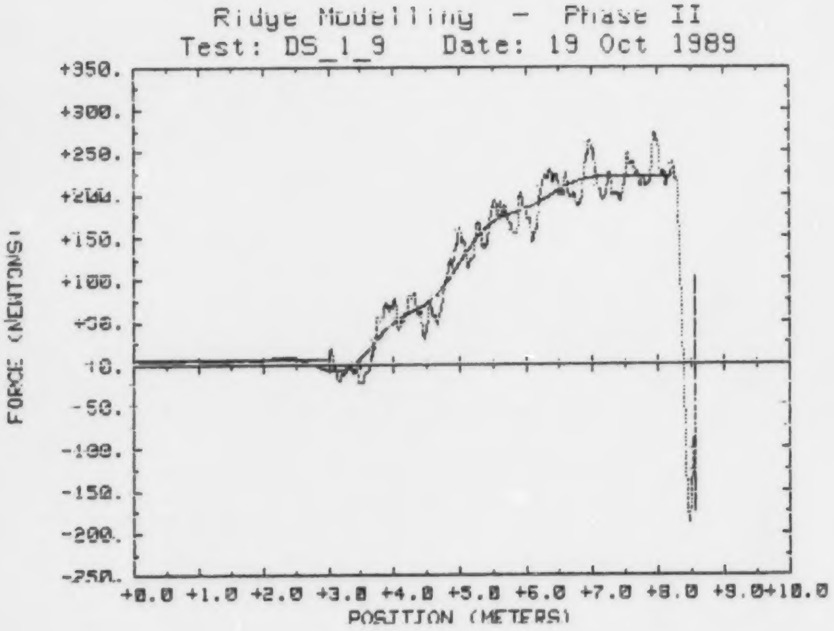


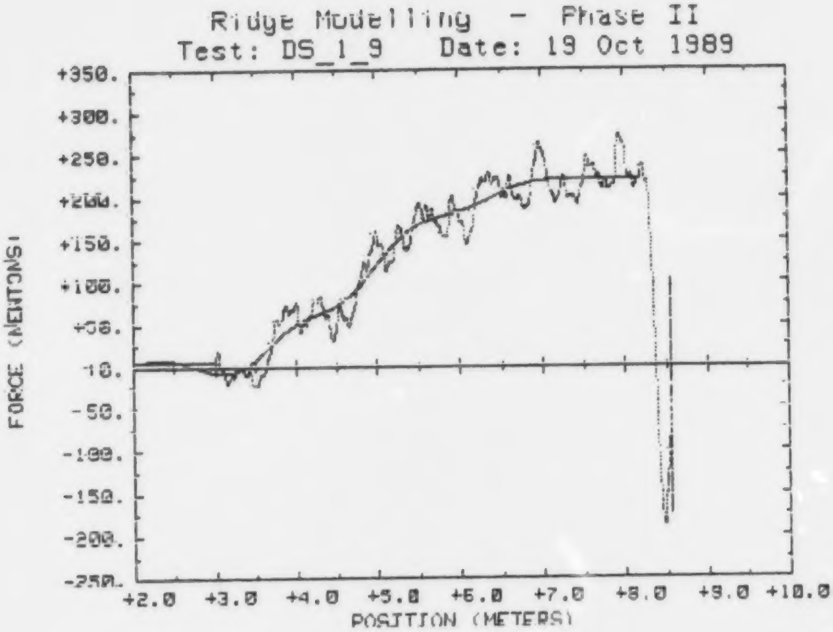
Ridge Modelling - Phase II
Test: DS_1_8 Date: 19 Oct 1989

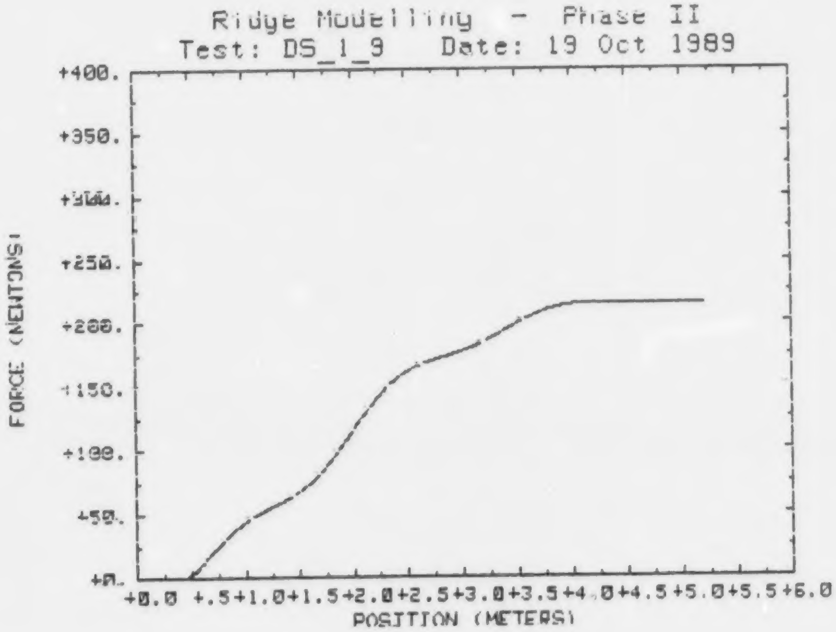

RIDGE MODELLING for DS 1 9
FORCE (NEWTONS)
300
200
100
0
-100
-200
10
15
20
25
30
35
40
Time (sec)


RIDGE MODELLING for DS 1 9
POSITION (METERS)
10
8
6
4
2
0
10
15
20
25
30
35
40
Time (sec)


RIDGE MODELLING
Project:3165C Test:DS_1_9
FORCE (NEWTONS)
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

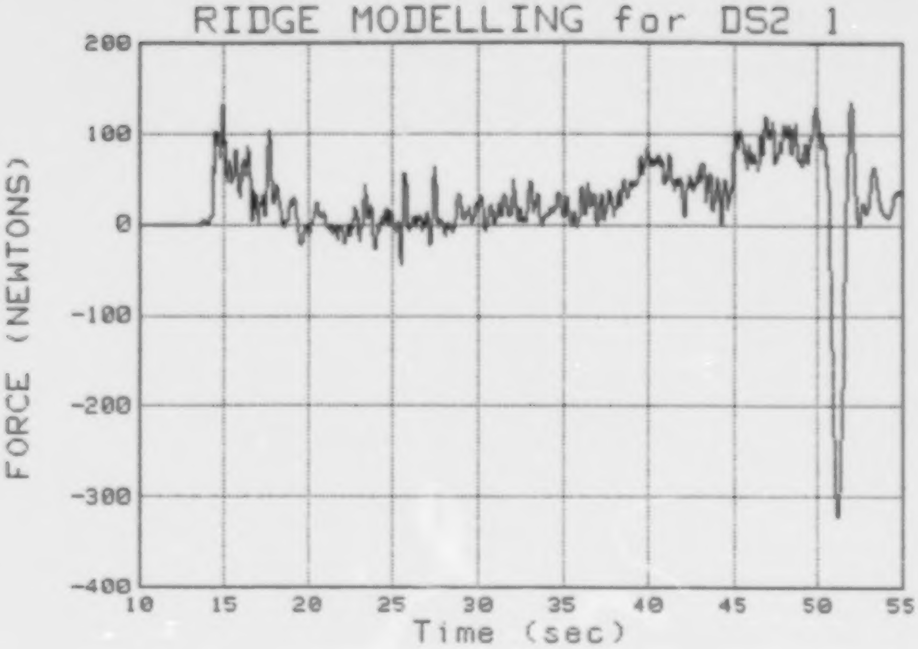

Ridge Modelling - Phase II
Test: DS_1_9 Date: 19 Oct 1989
FORCE (NEWTONS)
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

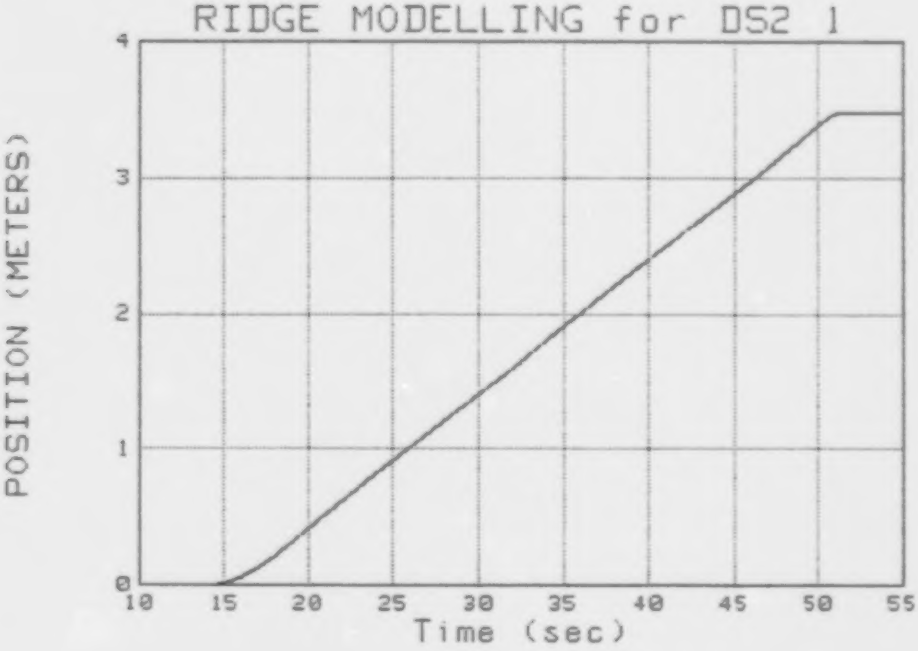

Ridge Modelling - Phase II
Test: DS_1_9 Date: 19 Oct 1989

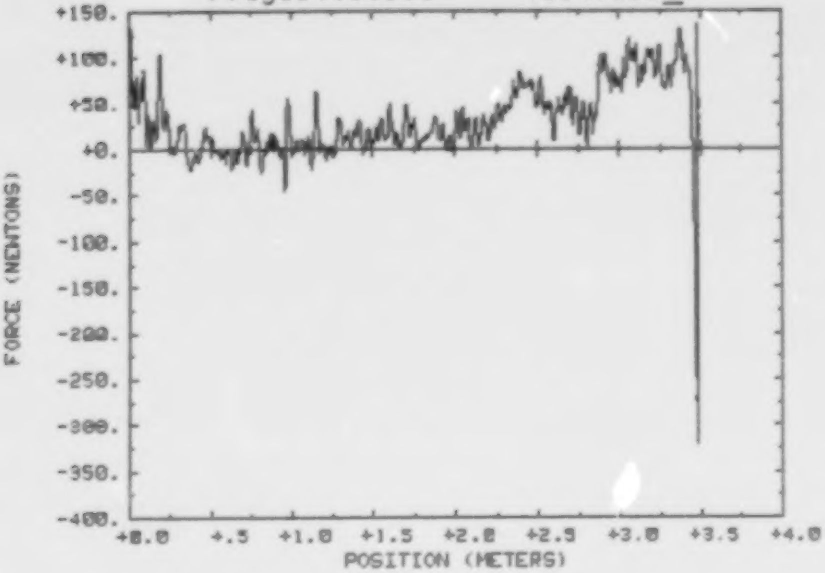

Ridge Modelling - Phase II
Test: DS_1_9 Date: 19 Oct 1989

APPENDIX I

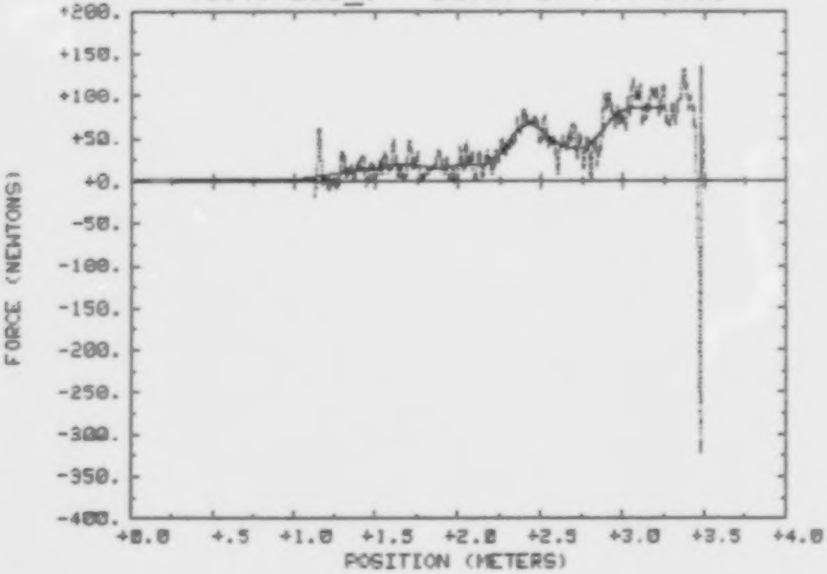
TEST DATA FOR SHEET #DS2


RIDGE MODELLING for DS2 1

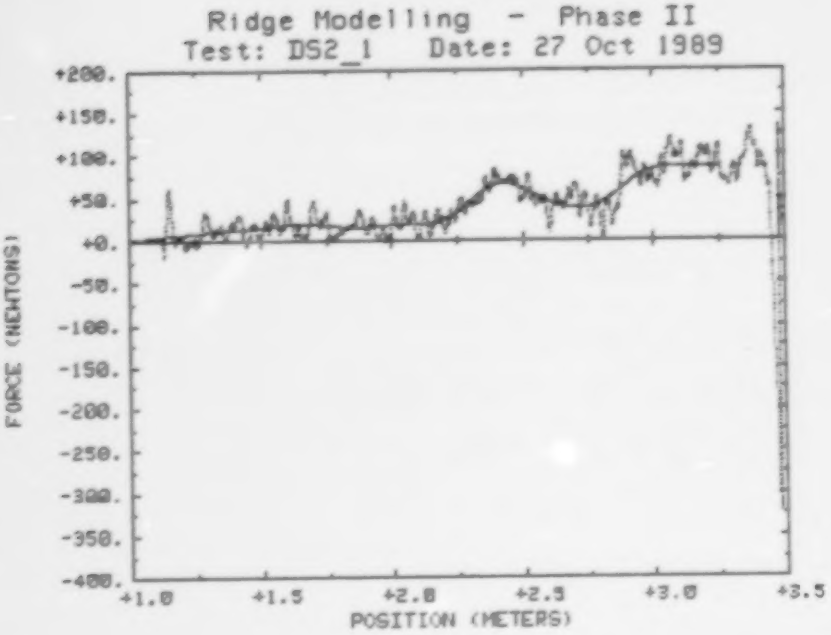

RIDGE MODELLING for DS2 1

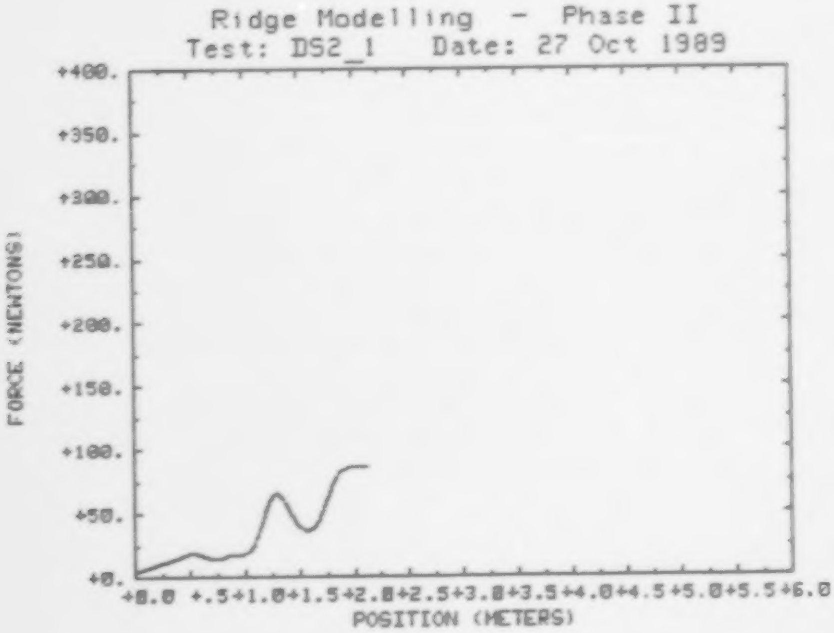


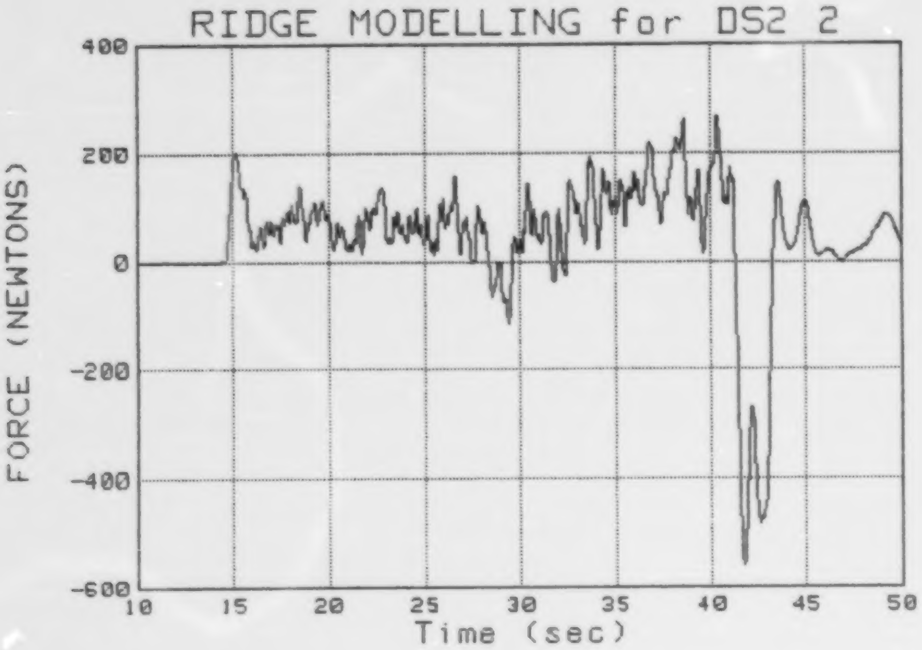
RIDGE MODELLING
Project:3165C Test:DS2_1

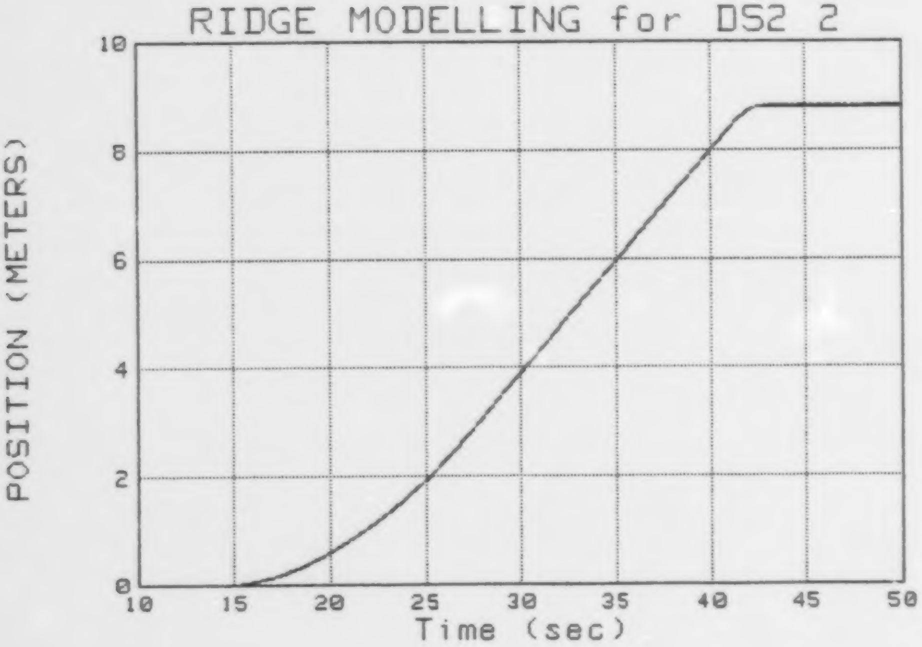


Ridge Modelling - Phase II
Test: DS2_1 Date: 27 Oct 1989

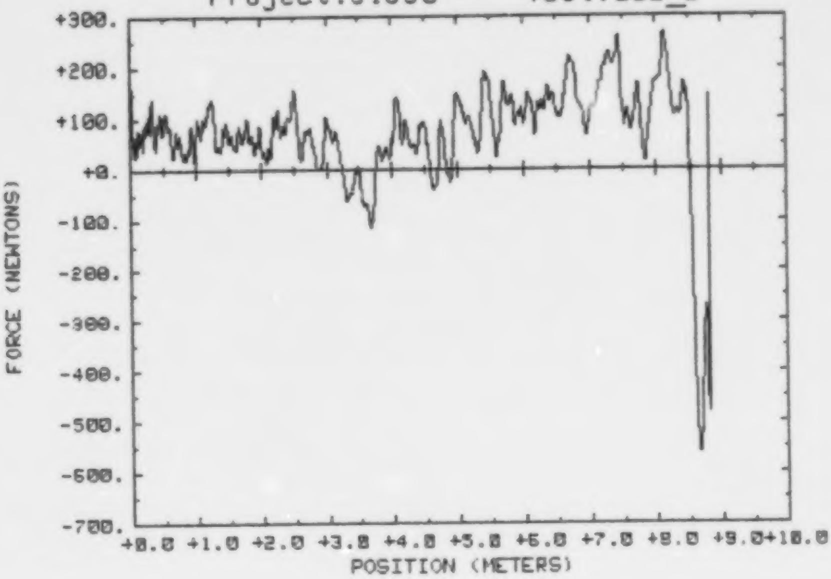

Ridge Modelling - Phase II
Test: DS2_1 Date: 27 Oct 1989
FORCE (NEWTONS)
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
-250.
-300.
-350.
-400.
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS2_1 Date: 27 Oct 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

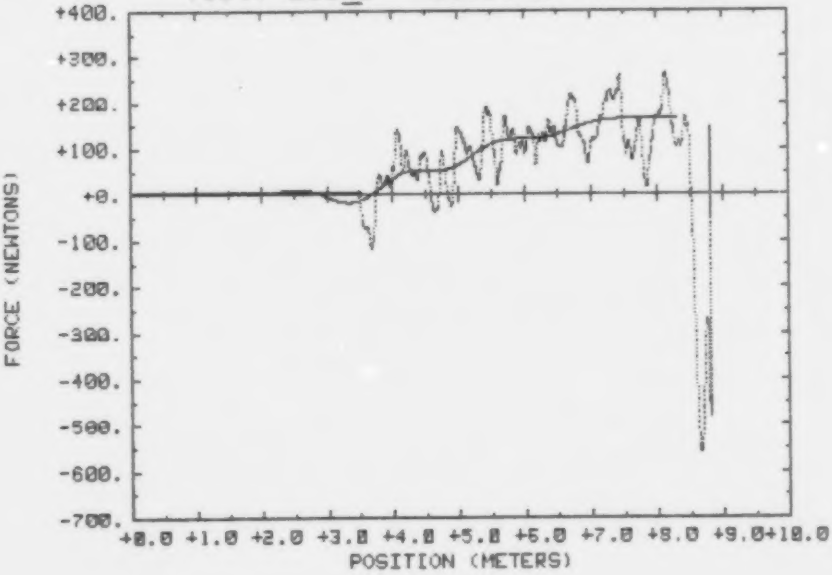

RIDGE MODELLING for DS2 2

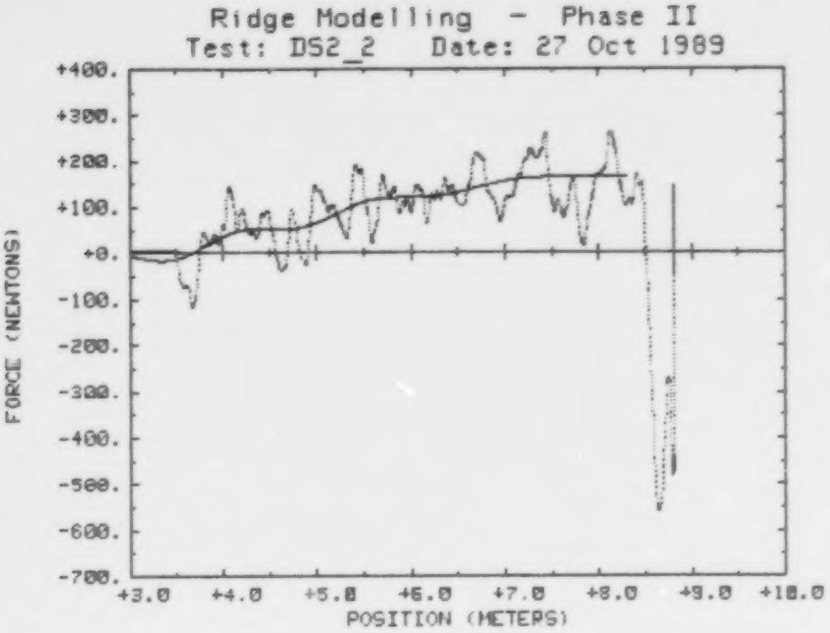

RIDGE MODELLING for DS2 2

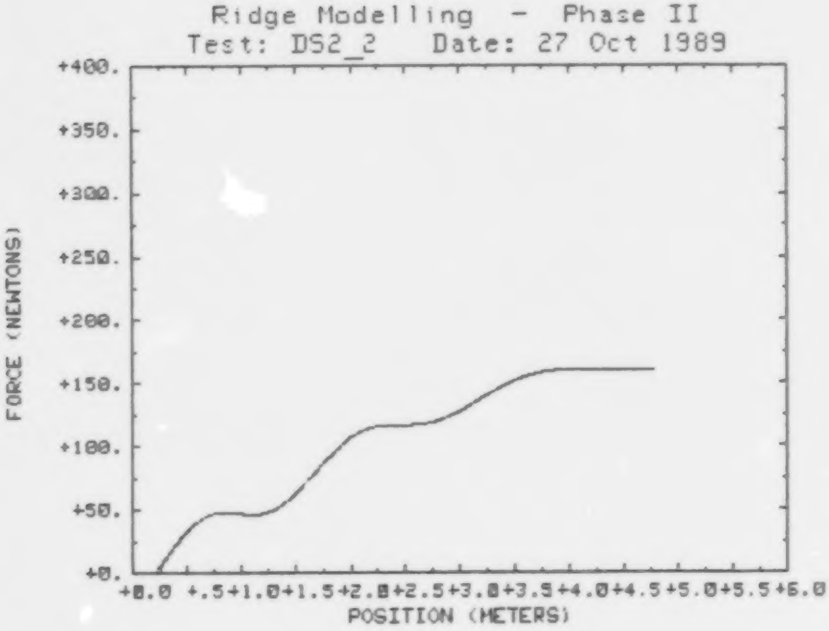
RIDGE MODELLING
Project:3165C Test:DS2_2

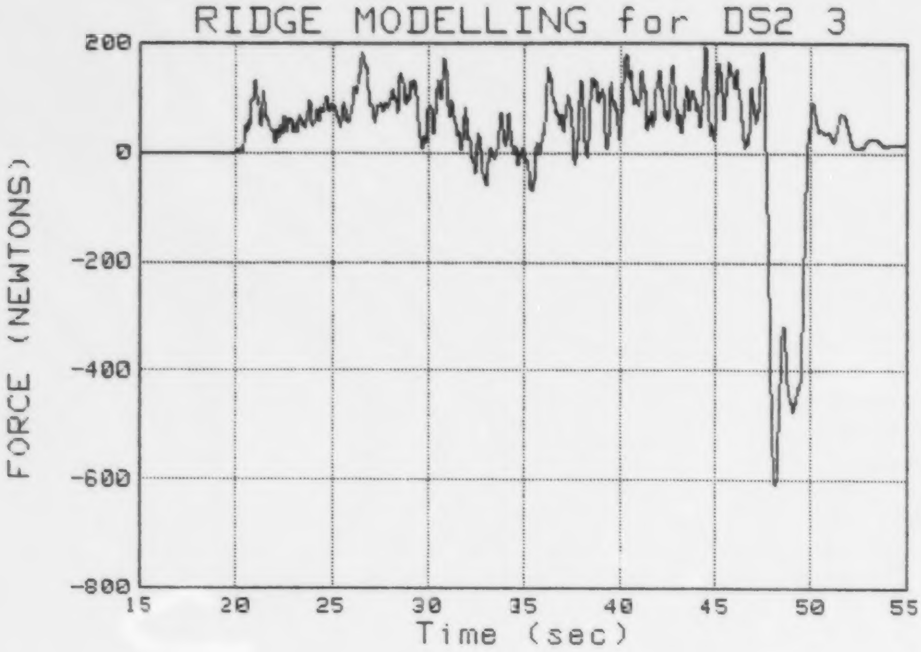


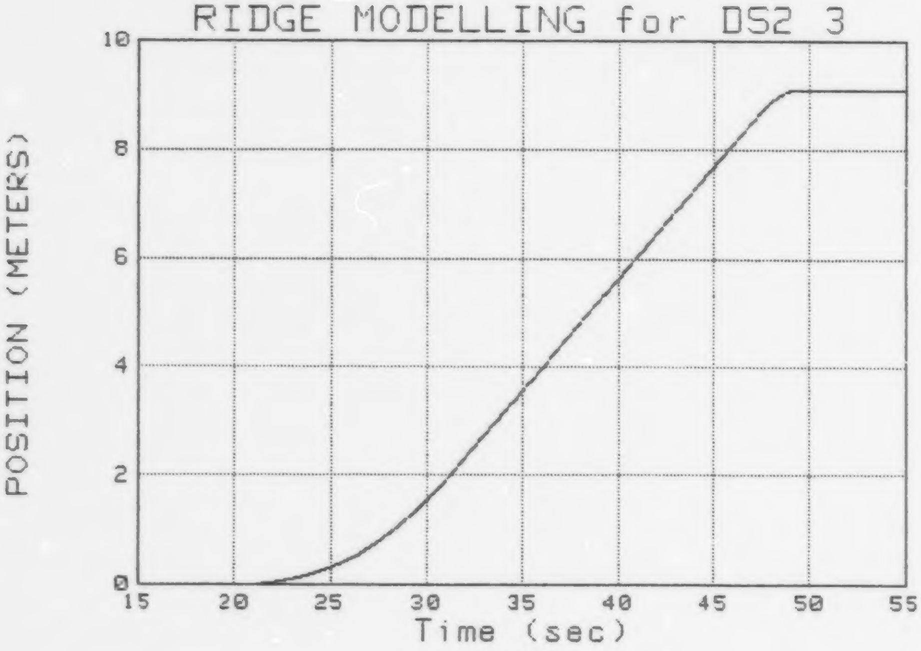
Ridge Modelling - Phase II
Test: DS2_2 Date: 27 Oct 1989

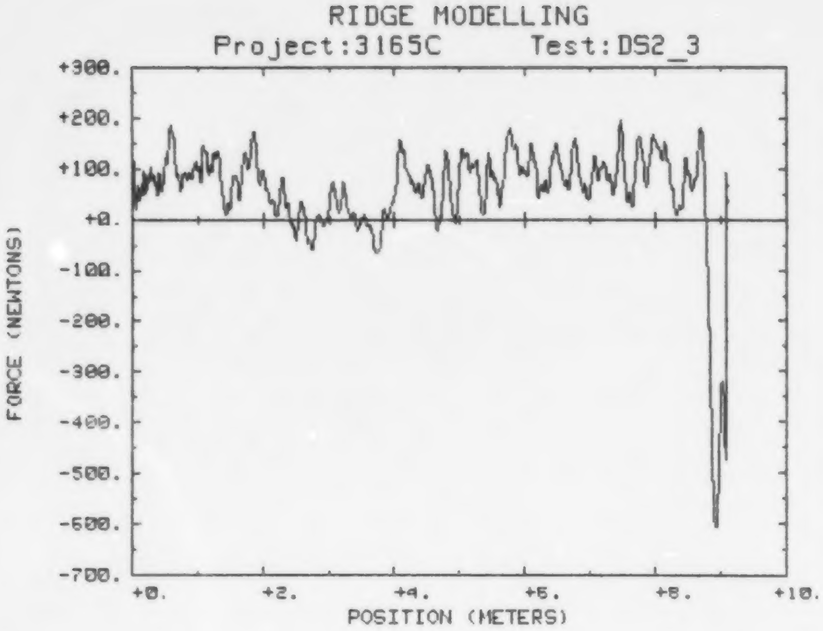



Ridge Modelling - Phase II
Test: DS2_2 Date: 27 Oct 1989
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
FORCE (NEWTONS)
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

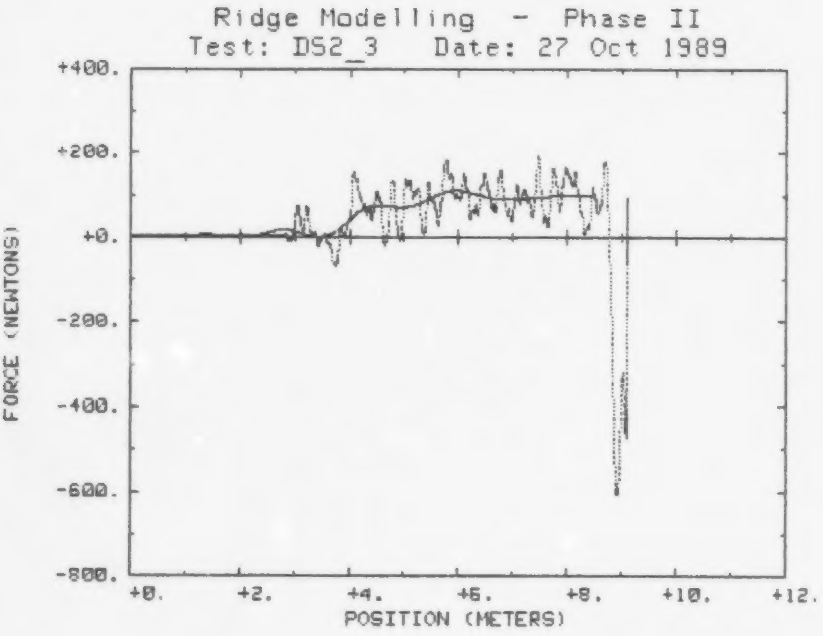

Ridge Modelling - Phase II
Test: DS2_2 Date: 27 Oct 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)


RIDGE MODELLING for DS2 3
FORCE (NEWTONS)
200
0
-200
-400
-600
-800
15
20
25
30
35
40
45
50
55
Time (sec)

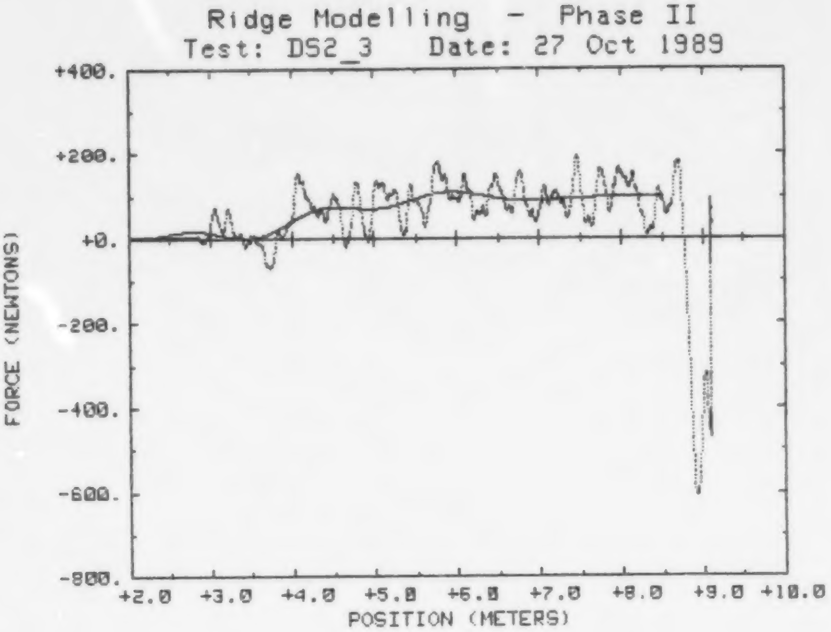

RIDGE MODELLING for DS2 3
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
45
50
55
Time (sec)

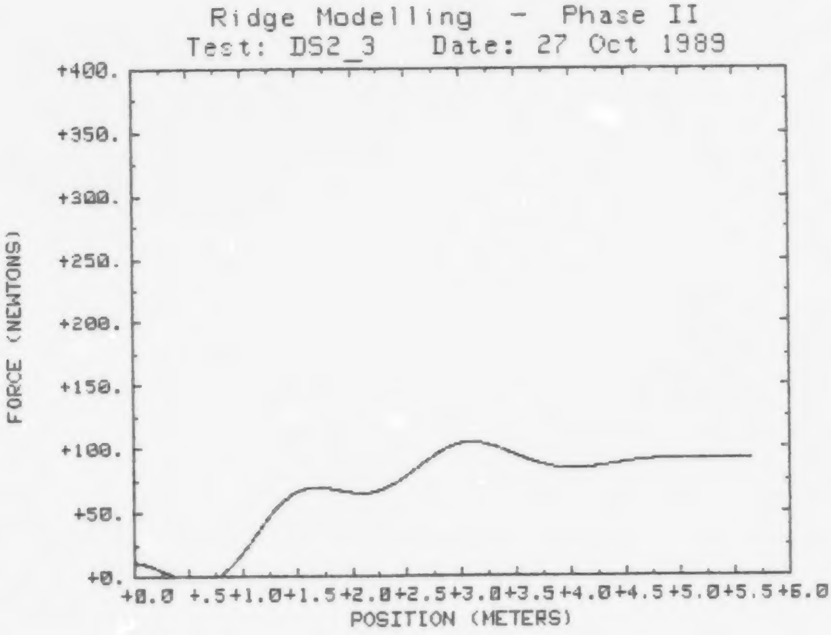


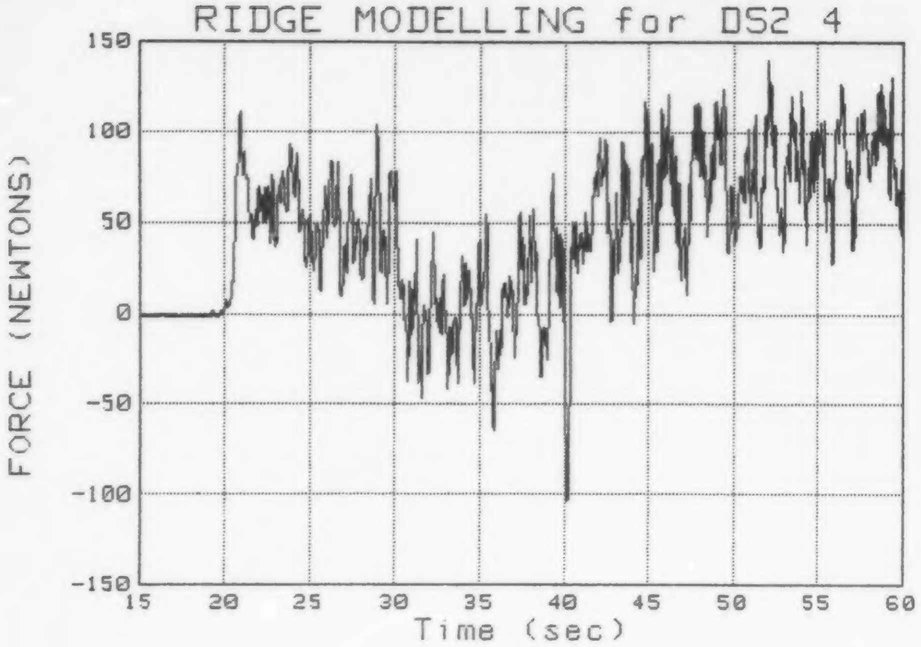
RIDGE MODELLING
Project:3165C Test:DS2_3

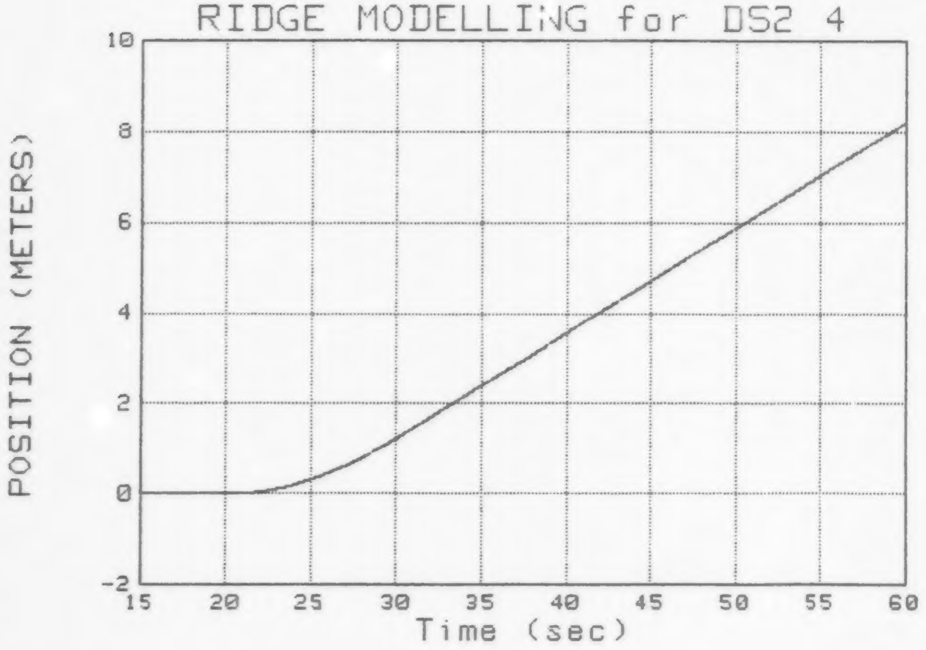


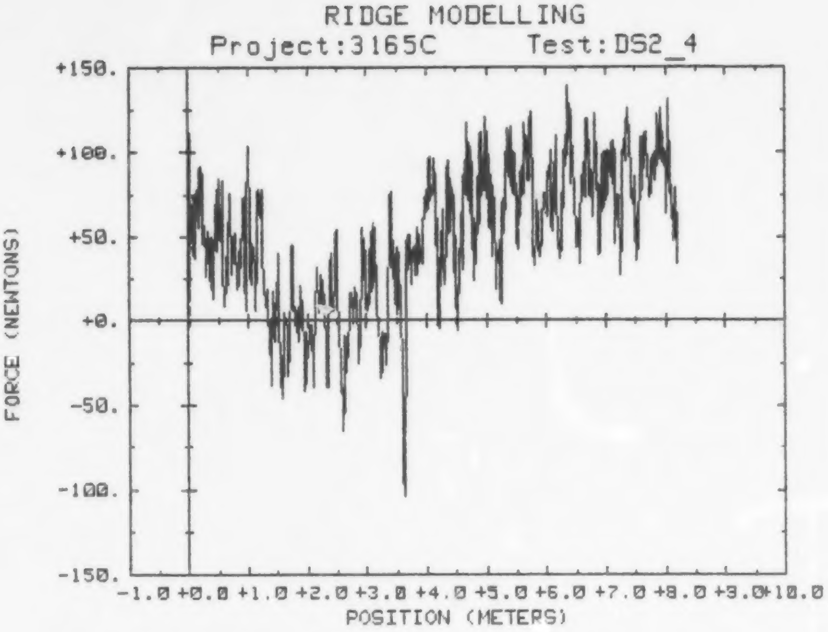
Ridge Modelling - Phase II
Test: DS2_3 Date: 27 Oct 1989

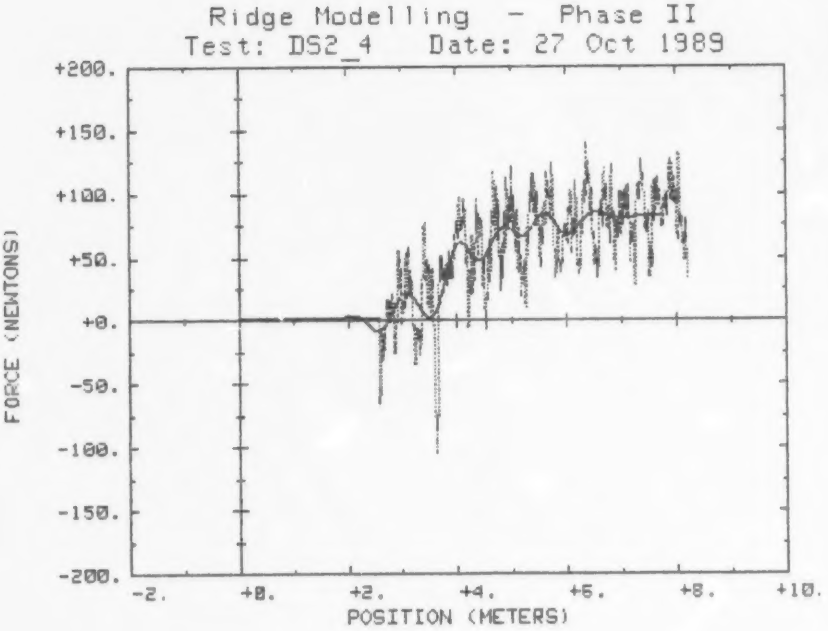

Ridge Modelling - Phase II
Test: DS2_3 Date: 27 Oct 1989
+400.
+200.
+0.
-200.
-400.
-600.
-800.
FORCE (NEWTONS)
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

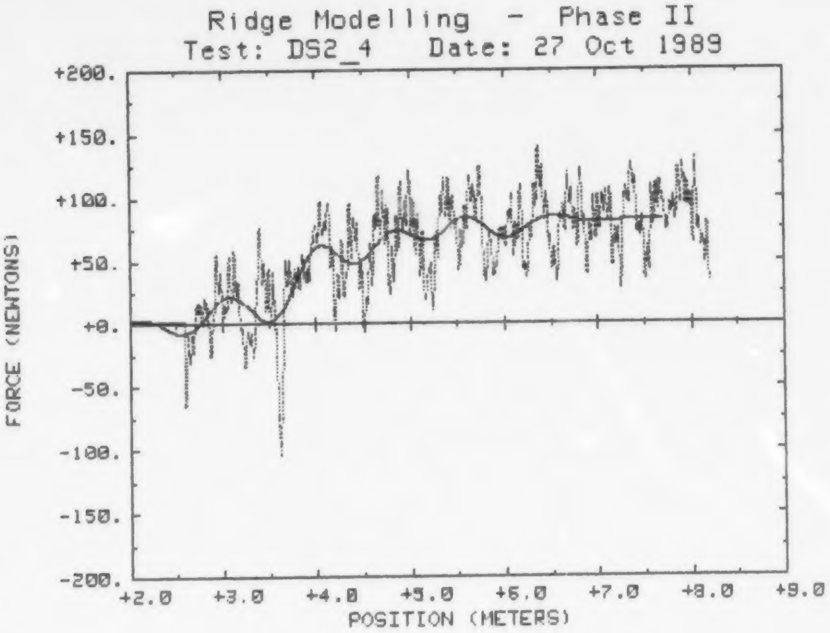

Ridge Modelling - Phase II
Test: DS2_3 Date: 27 Oct 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

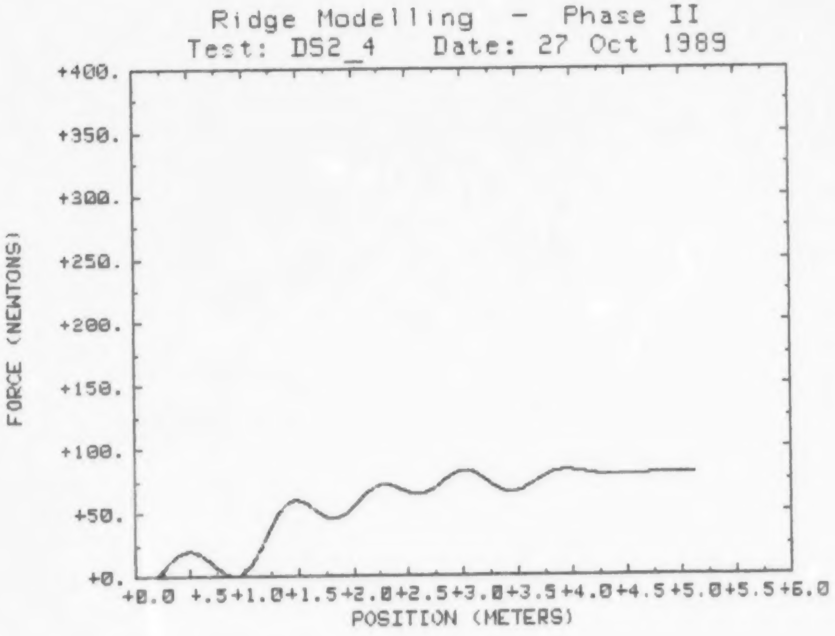

RIDGE MODELLING for DS2 4
FORCE (NEWTONS)
150
100
50
0
-50
-100
-150
15
20
25
30
35
40
45
50
55
60
Time (sec)

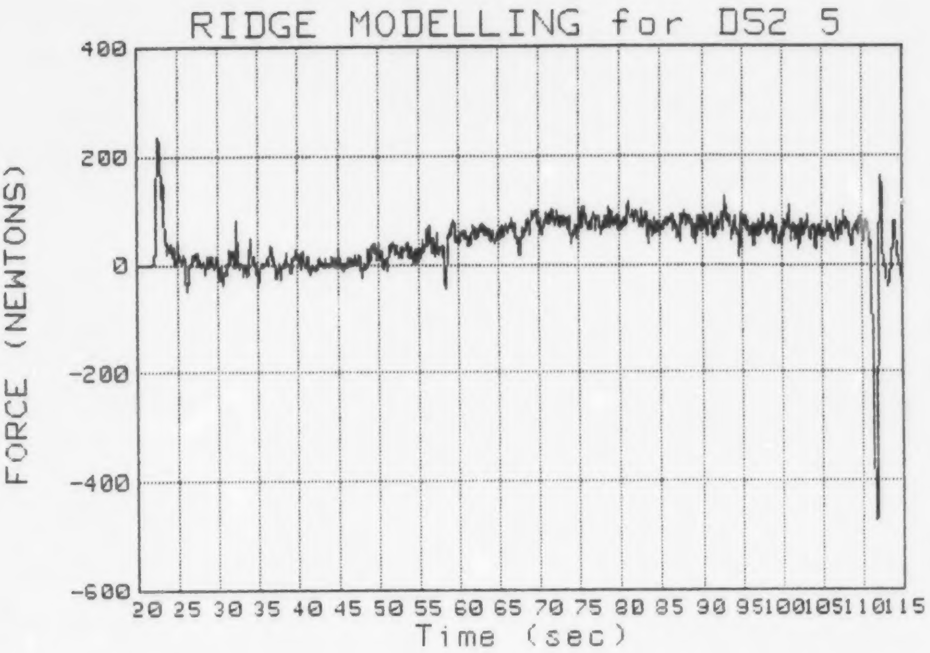

RIDGE MODELLING for DS2 4
POSITION (METERS)
10
8
6
4
2
0
-2
15
20
25
30
35
40
45
50
55
60
Time (sec)

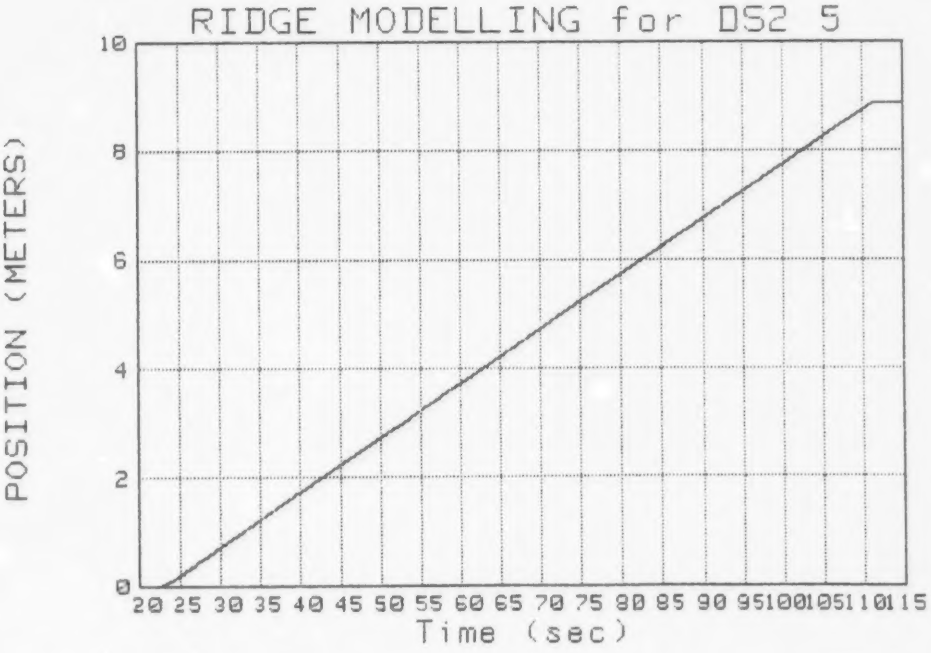

RIDGE MODELLING
Project:3165C Test:DS2_4
+150.
+100.
+50.
+0.
-50.
-100.
-150.
FORCE (NEWTONS)
-1.0 +0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

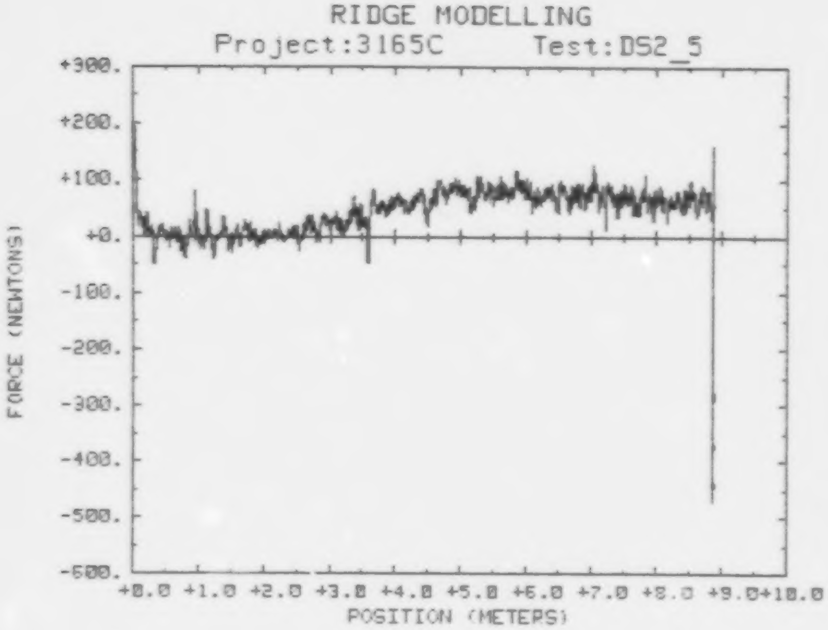

Ridge Modelling - Phase II
Test: DS2_4 Date: 27 Oct 1989
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
FORCE (NEWTONS)
-2. +0. +2. +4. +6. +8. +10.
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS2_4 Date: 27 Oct 1989
FORCE (NEWTONS)
+200.
+150.
+100.
+50.
+0.
-50.
-100.
-150.
-200.
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
POSITION (METERS)

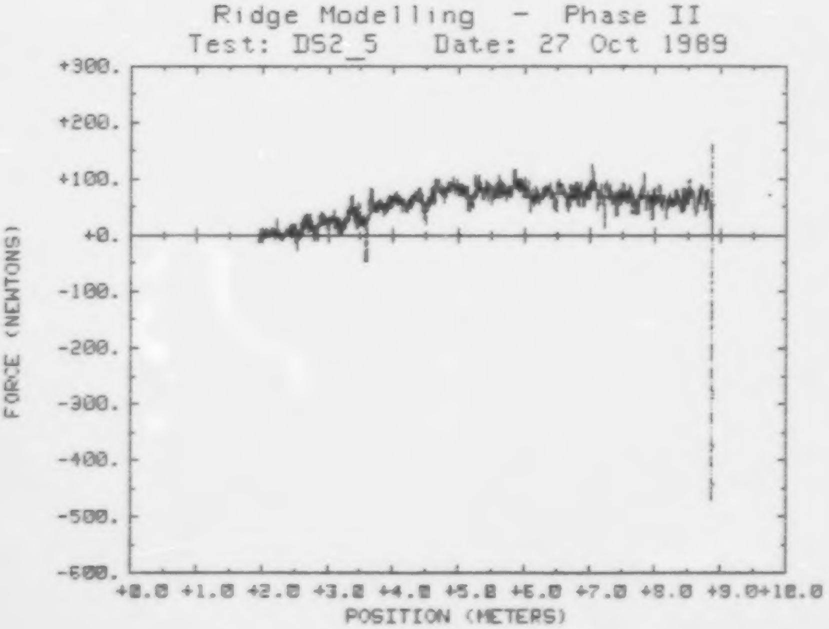

Ridge Modelling - Phase II
Test: DS2_4 Date: 27 Oct 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)


RIDGE MODELLING for DS2 5
FORCE (NEWTONS)
400
200
0
-200
-400
-600
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115
Time (sec)

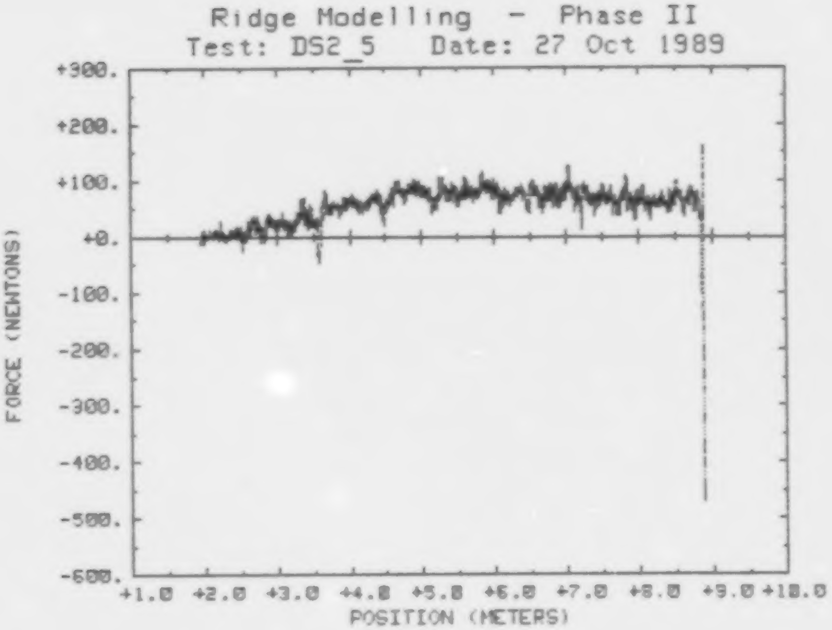

RIDGE MODELLING for DS2 5
POSITION (METERS)
10
8
6
4
2
0
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115
Time (sec)

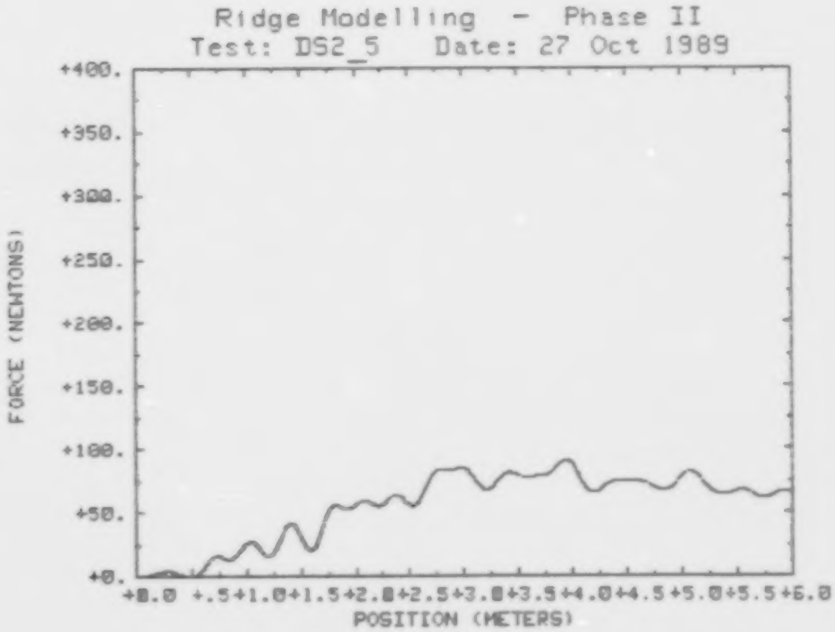


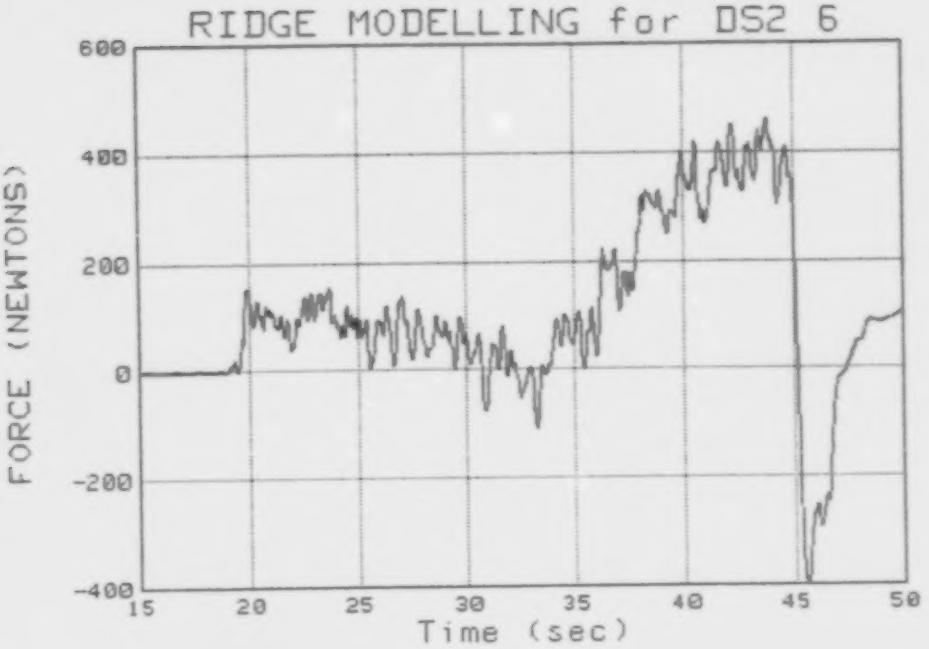
RIDGE MODELLING
Project:3165C Test:DS2_5

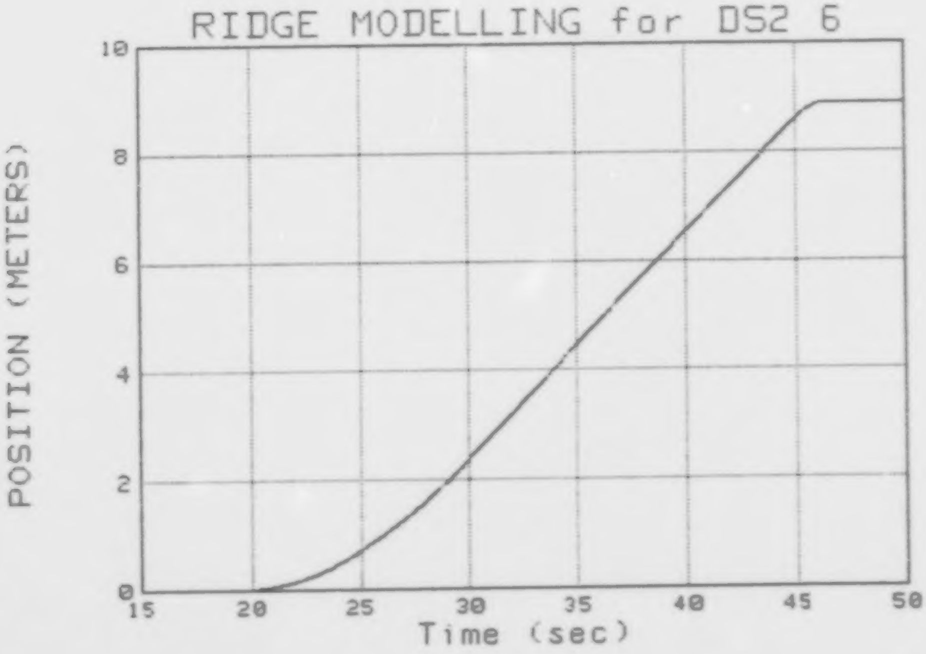


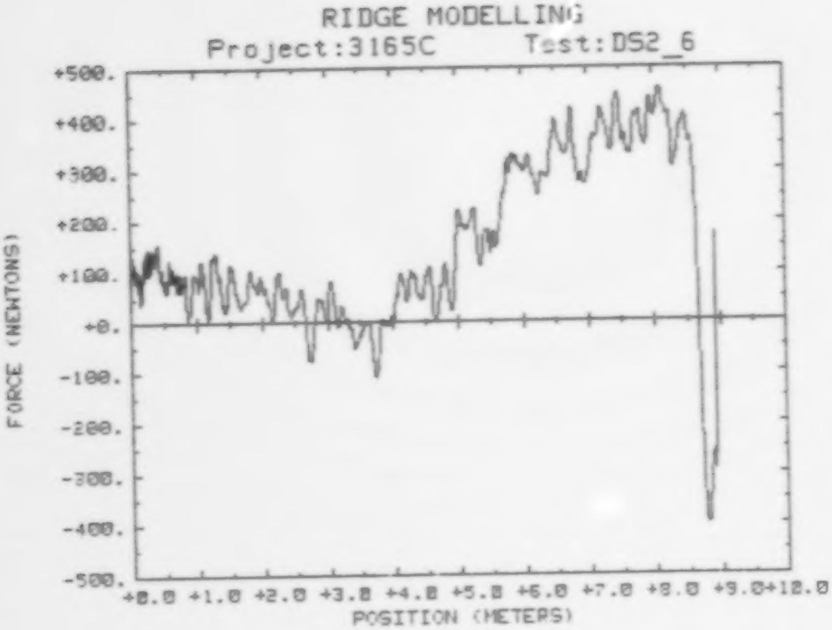
Ridge Modelling - Phase II
Test: DS2_5 Date: 27 Oct 1989

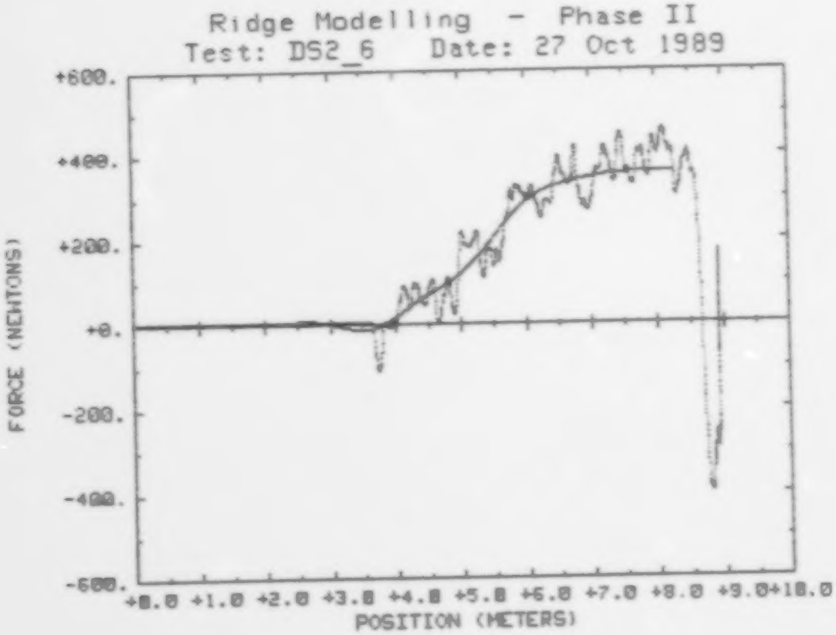

Ridge Modelling - Phase II
Test: DS2_5 Date: 27 Oct 1989
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

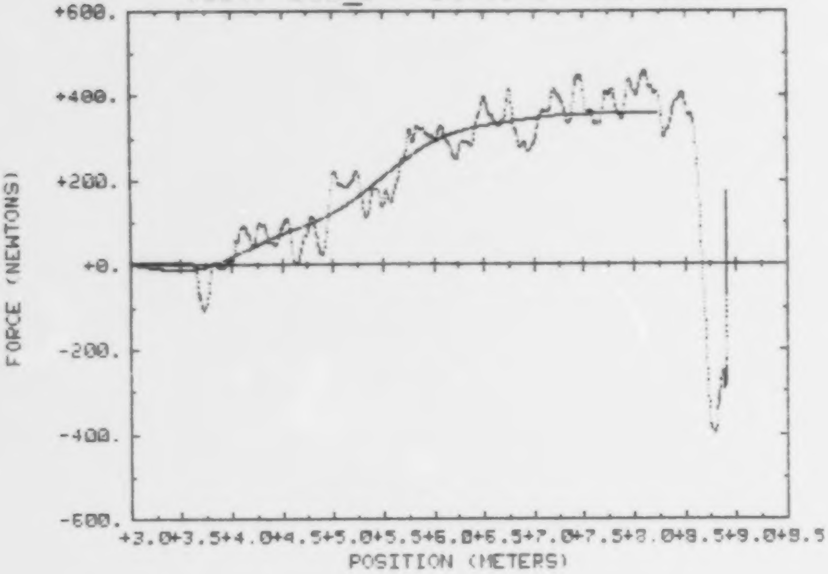

Ridge Modelling - Phase II
Test: DS2_5 Date: 27 Oct 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

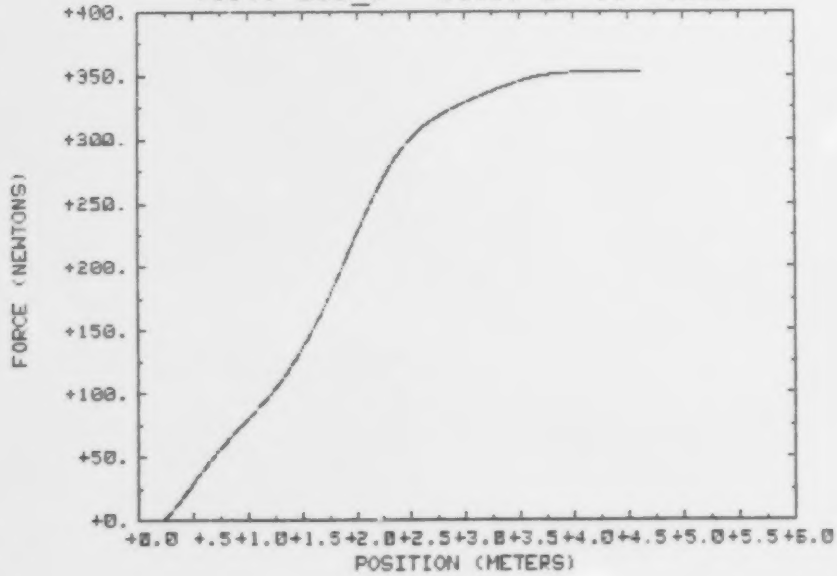

RIDGE MODELLING for DS2 6
FORCE (NEWTONS)
600
400
200
0
-200
-400
15
20
25
30
35
40
45
50
Time (sec)

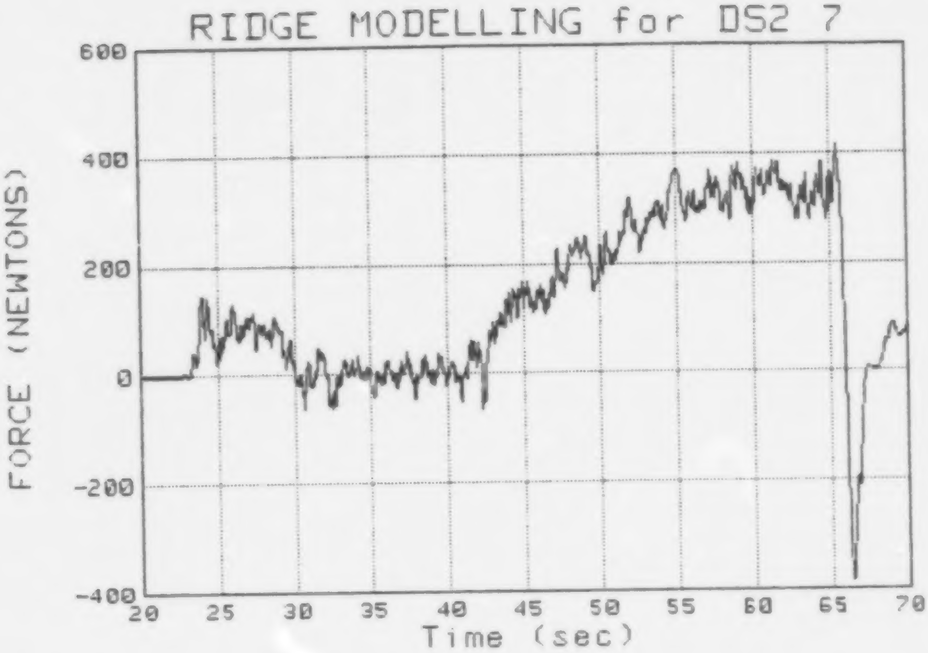

RIDGE MODELLING for DS2 6
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
45
50
Time (sec)

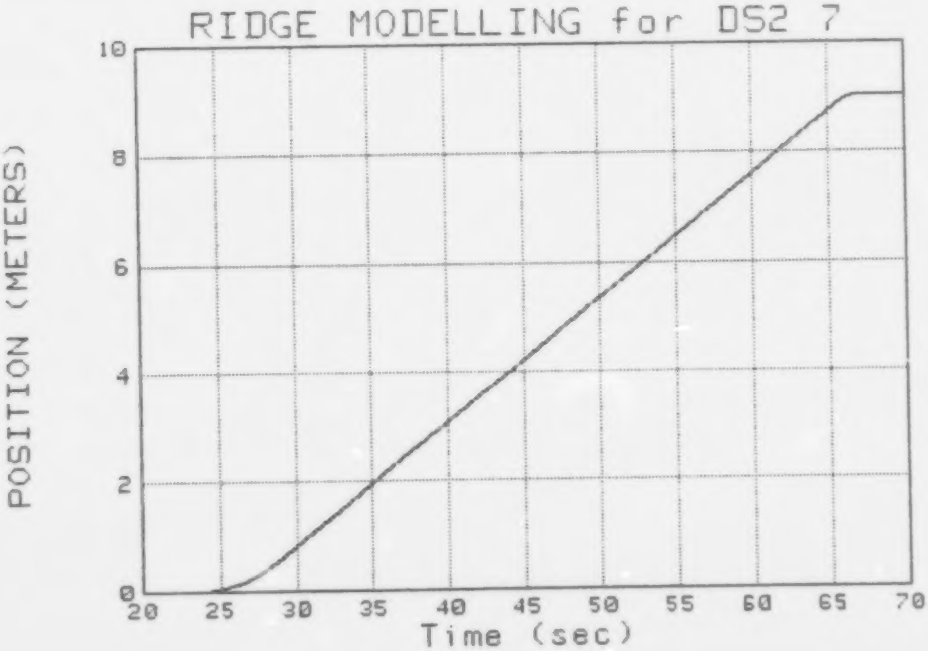

RIDGE MODELLING
Project:3165C Test:DS2_6
FORCE (NEWTONS)
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)

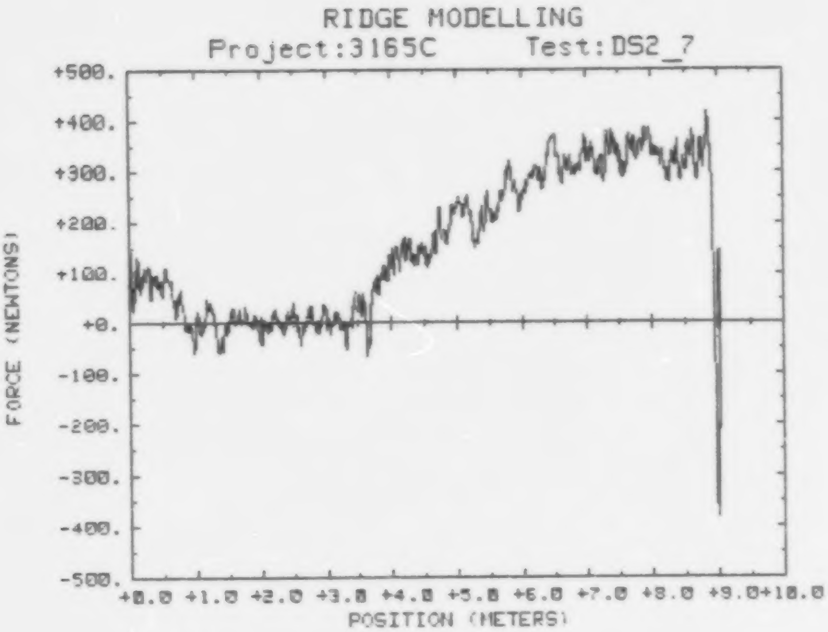

Ridge Modelling - Phase II
Test: DS2_6 Date: 27 Oct 1989
FORCE (NEWTONS)
+600.
+400.
+200.
+0.
-200.
-400.
-600.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)

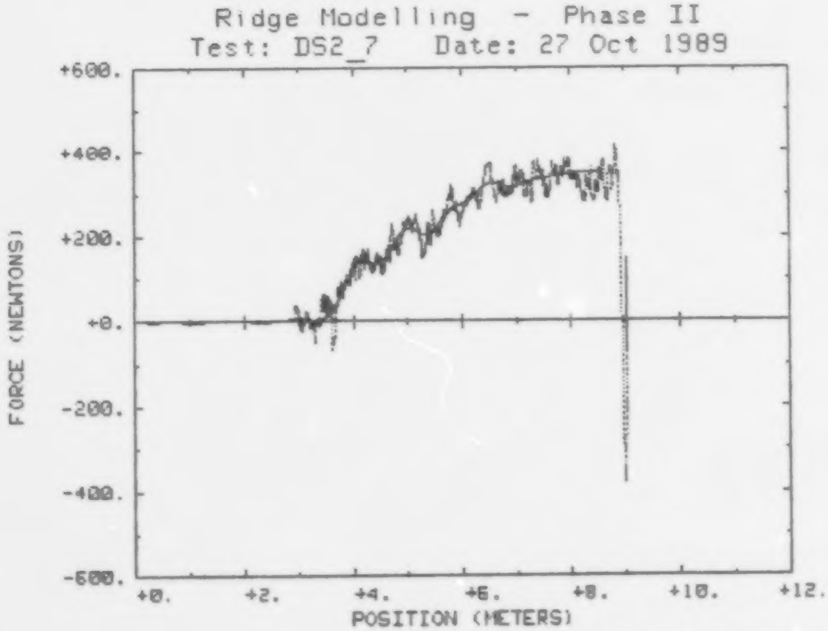

Ridge Modelling - Phase II
Test: DS2_6 Date: 27 Oct 1989

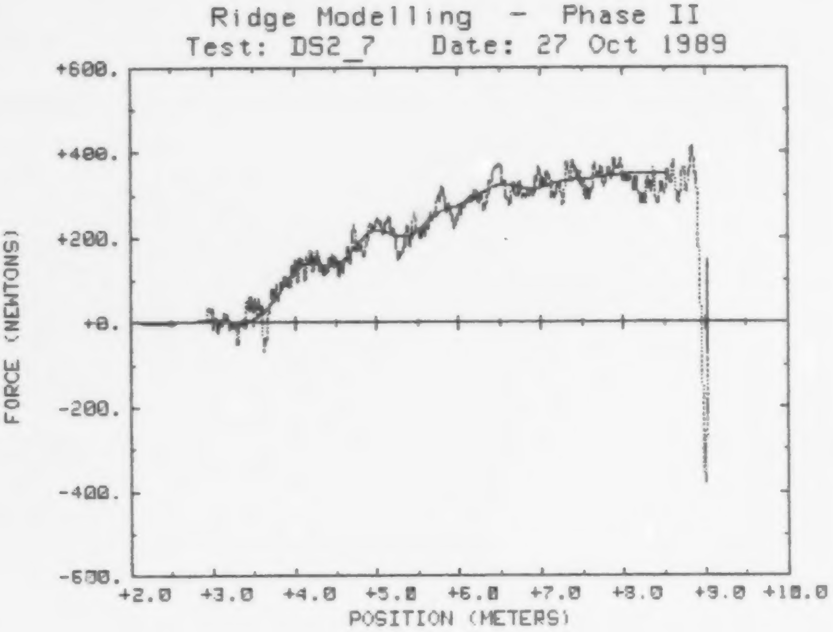

Ridge Modelling - Phase II
Test: DS2_6 Date: 27 Oct 1989

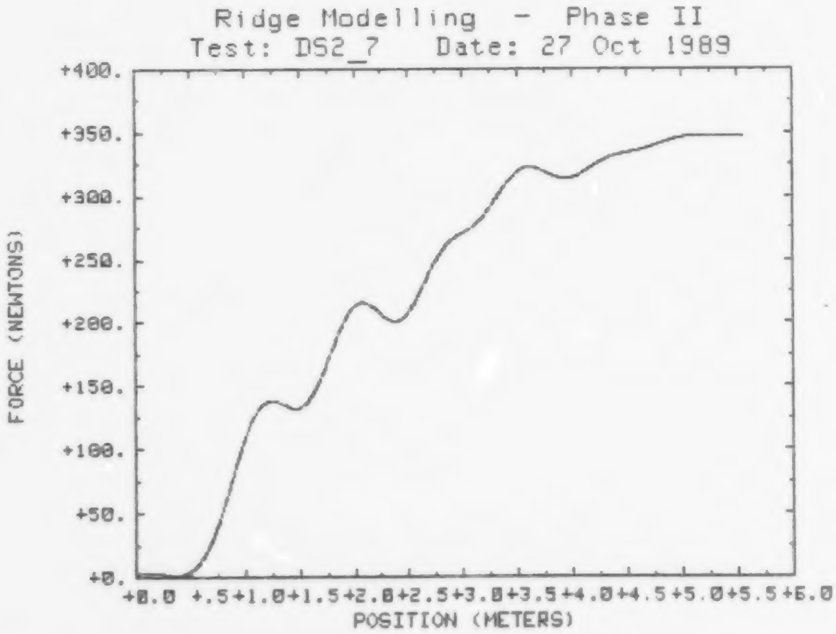

RIDGE MODELLING for DS2 7
FORCE (NEWTONS)
600
400
200
0
-200
-400
20
25
30
35
40
45
50
55
60
65
70
Time (sec)

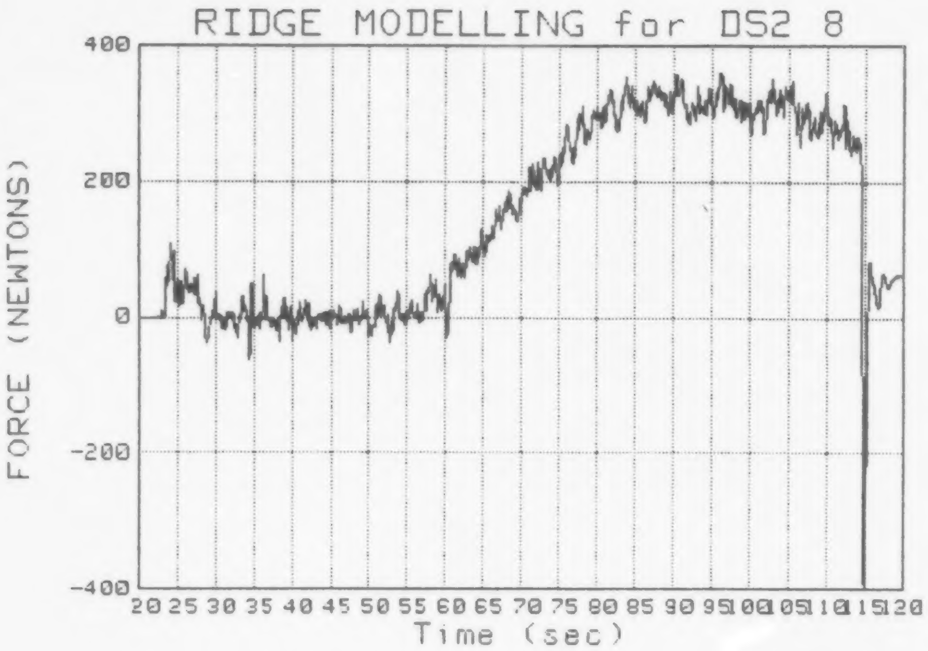

RIDGE MODELLING for DS2 7
POSITION (METERS)
10
8
6
4
2
0
20
25
30
35
40
45
50
55
60
65
70
Time (sec)


RIDGE MODELLING
Project:3165C Test:DS2_7
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
FORCE (NEWTONS)
+0.0
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

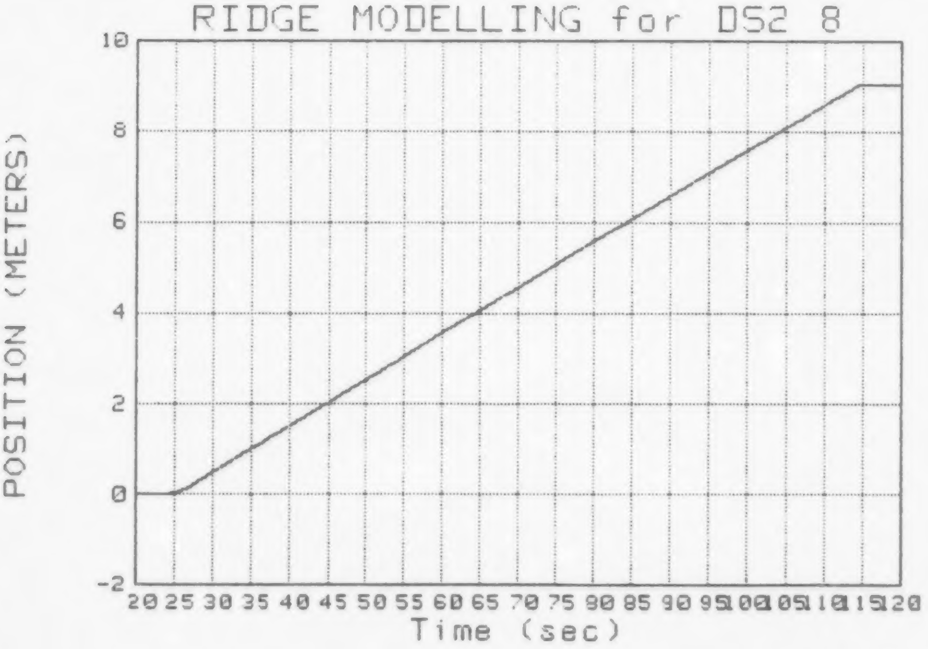

Ridge Modelling - Phase II
Test: DS2_7 Date: 27 Oct 1989
+600.
+400.
+200.
+0.
-200.
-400.
-600.
FORCE (NEWTONS)
+0.
+2.
+4.
+6.
+8.
+10.
+12.
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS2_7 Date: 27 Oct 1989
+600.
+400.
+200.
+0.
-200.
-400.
-600.
FORCE (NEWTONS)
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS2_7 Date: 27 Oct 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

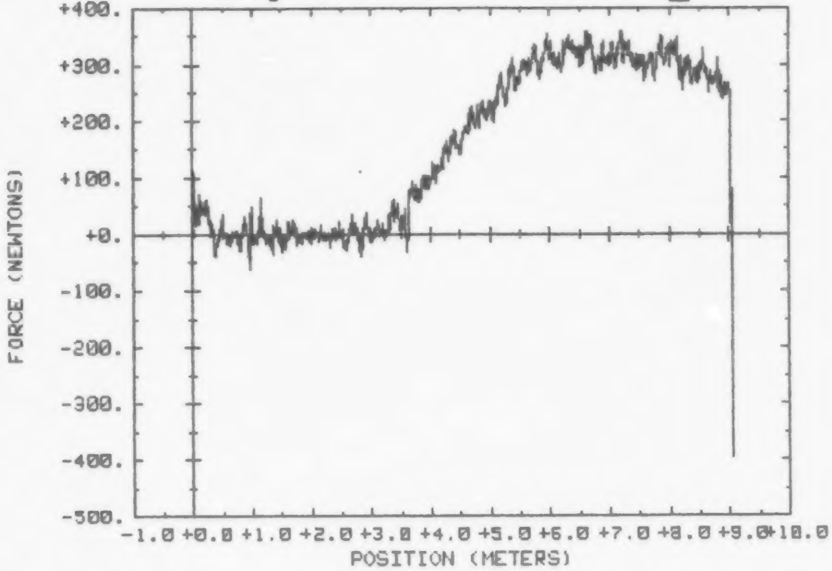


RIDGE MODELLING for DS2 8

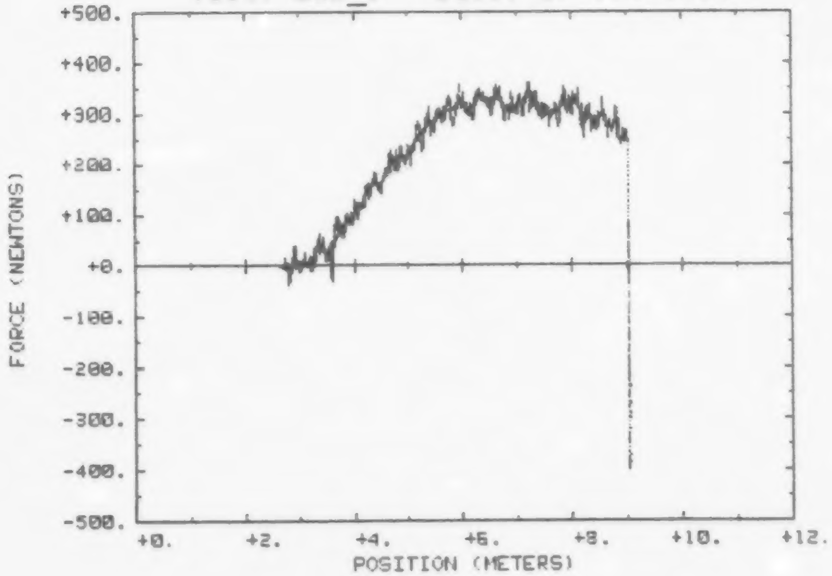


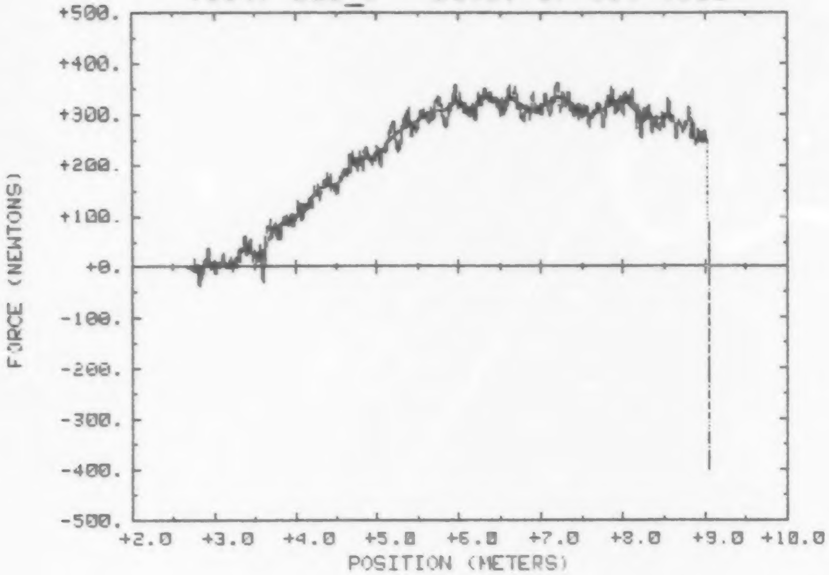
RIDGE MODELLING for DS2 8

RIDGE MODELLING
Project:3165C Test:DS2_8

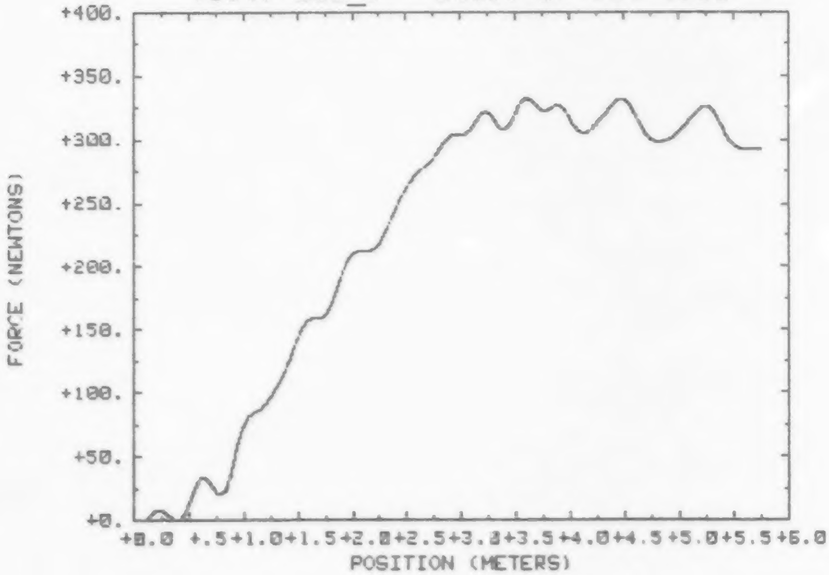


Ridge Modelling - Phase II
Test: DS2_8 Date: 27 Oct 1989





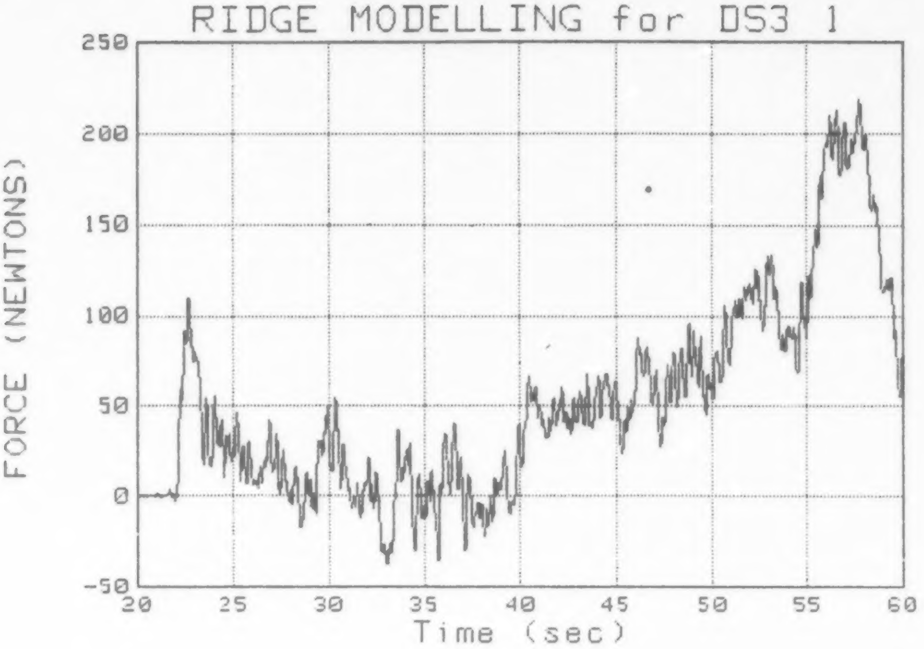
Ridge Modelling - Phase II
Test: DS2_8 Date: 27 Oct 1989

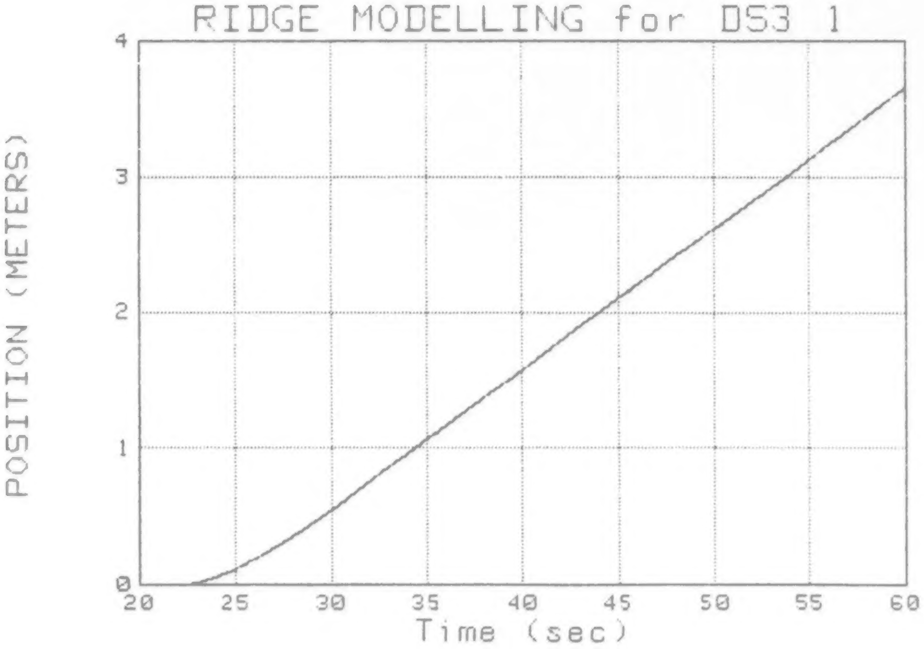


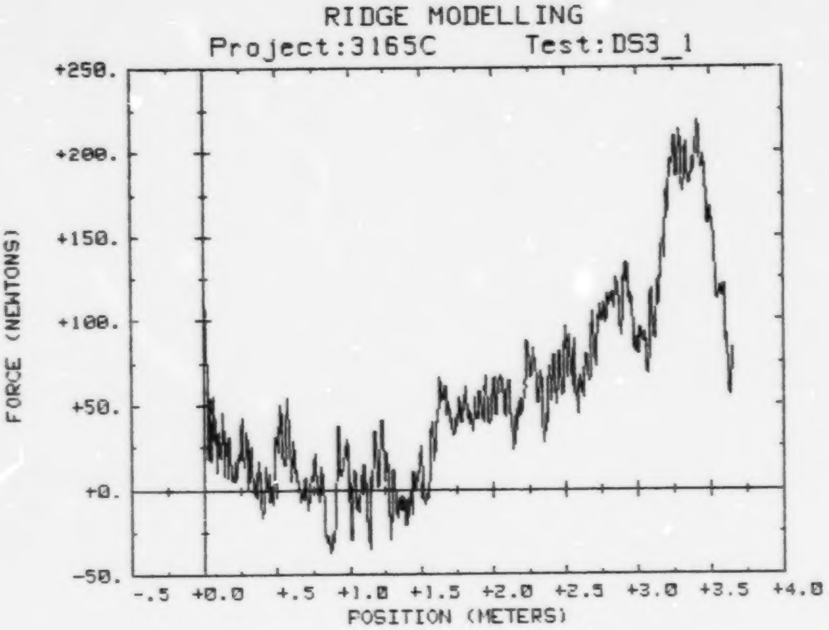
Ridge Modelling - Phase II
Test: DS2_8 Date: 27 Oct 1989

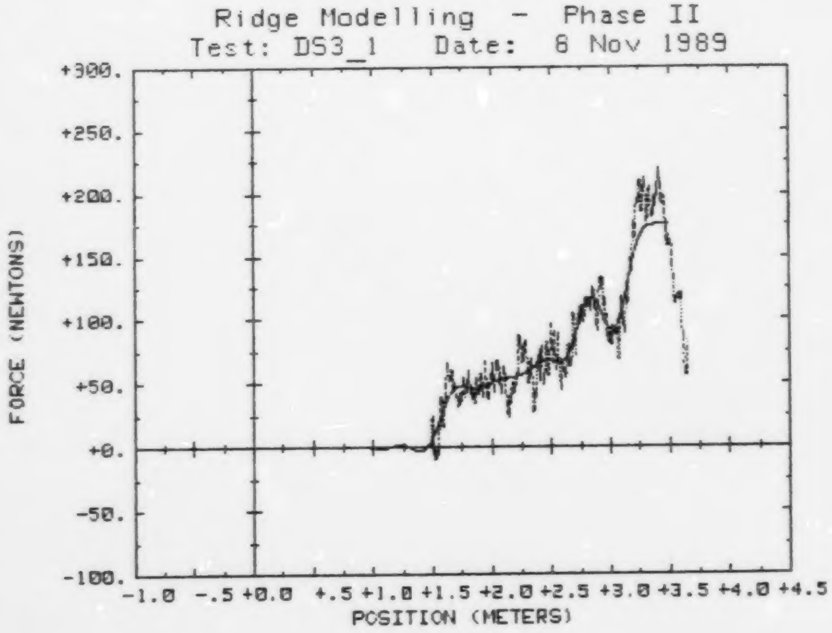
APPENDIX J

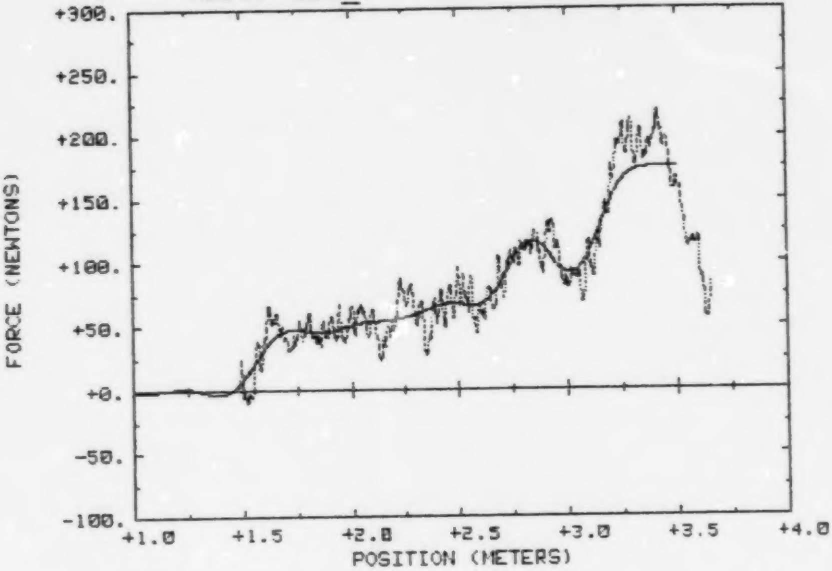
TEST DATA FOR SHEET #DS3


RIDGE MODELLING for DS3 1
FORCE (NEWTONS)
250
200
150
100
50
0
-50
20
25
30
35
40
45
50
55
60
Time (sec)

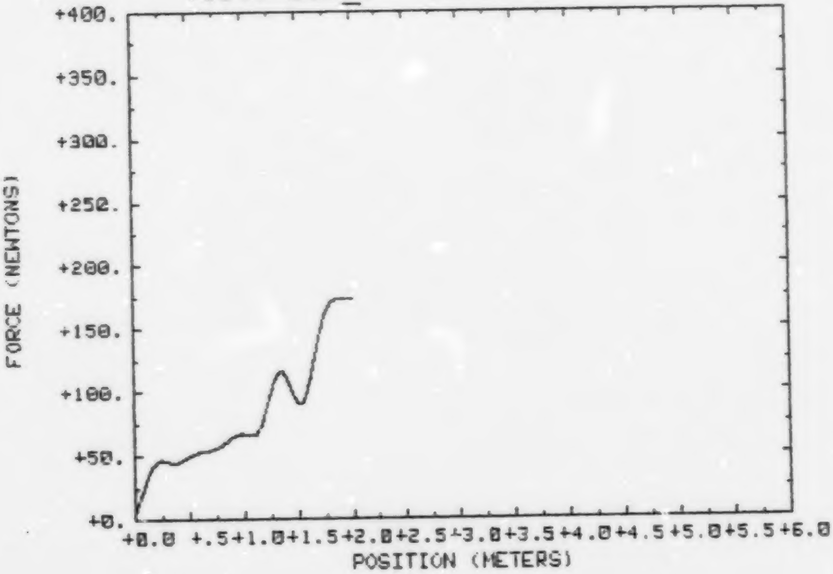

RIDGE MODELLING for DS3 1
POSITION (METERS)
4
3
2
1
0
20
25
30
35
40
45
50
55
60
Time (sec)


RIDGE MODELLING
Project:3165C Test:DS3_1

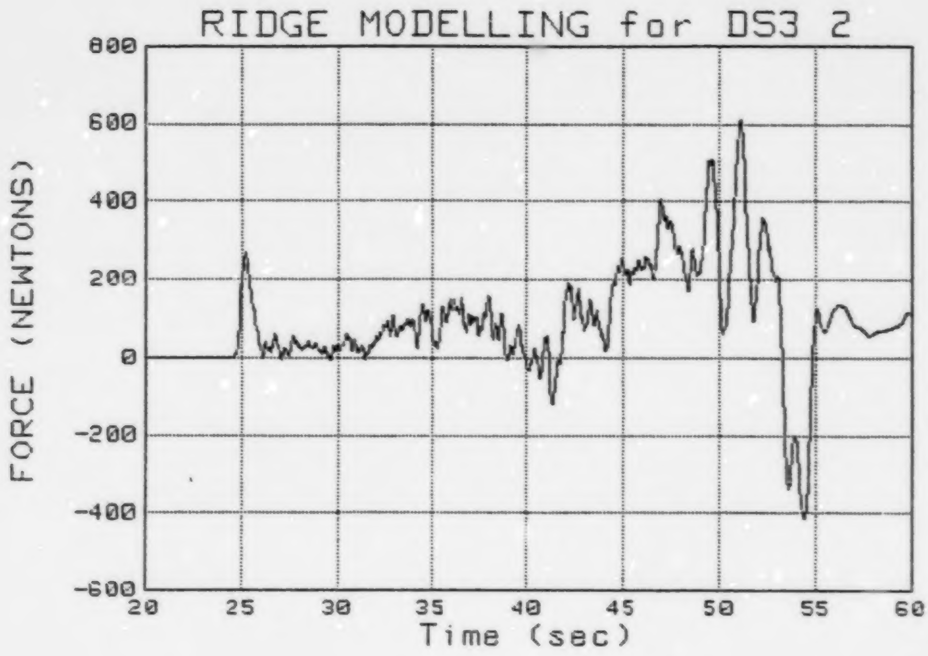

Ridge Modelling - Phase II
Test: DS3_1 Date: 6 Nov 1989

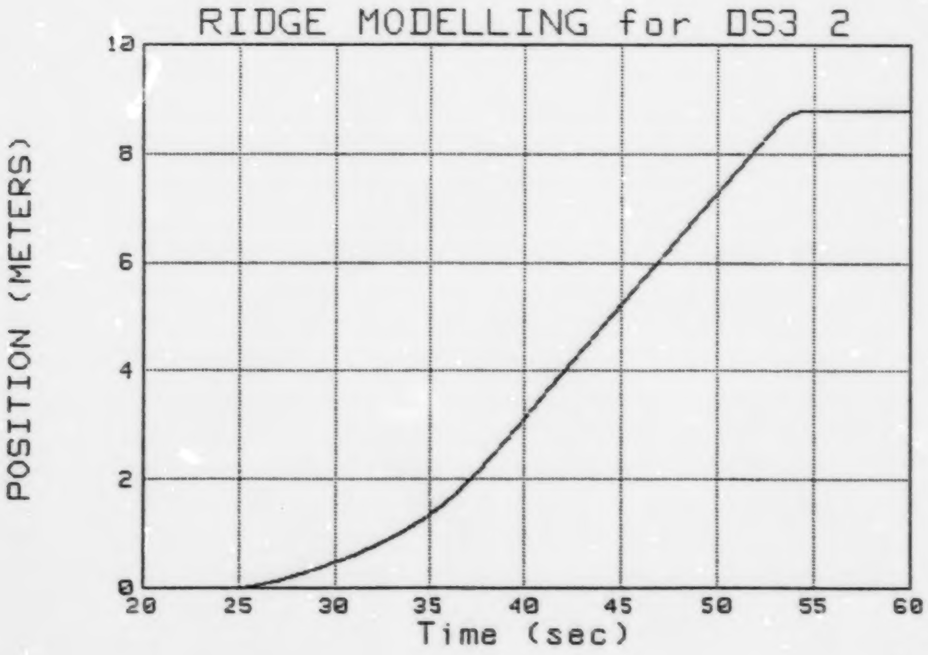


Ridge Modelling - Phase II
Test: DS3_1 Date: 8 Nov 1989

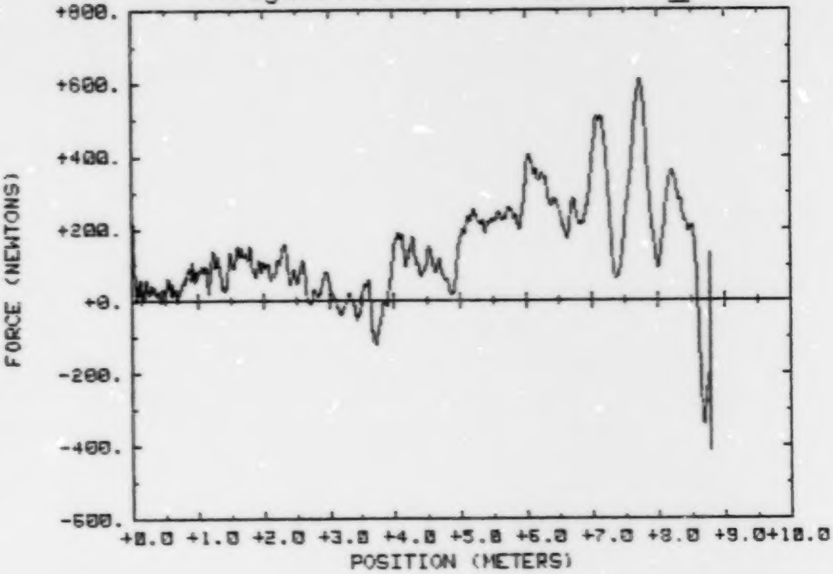


Ridge Modelling - Phase II
Test: DS3_1 Date: 8 Nov 1989

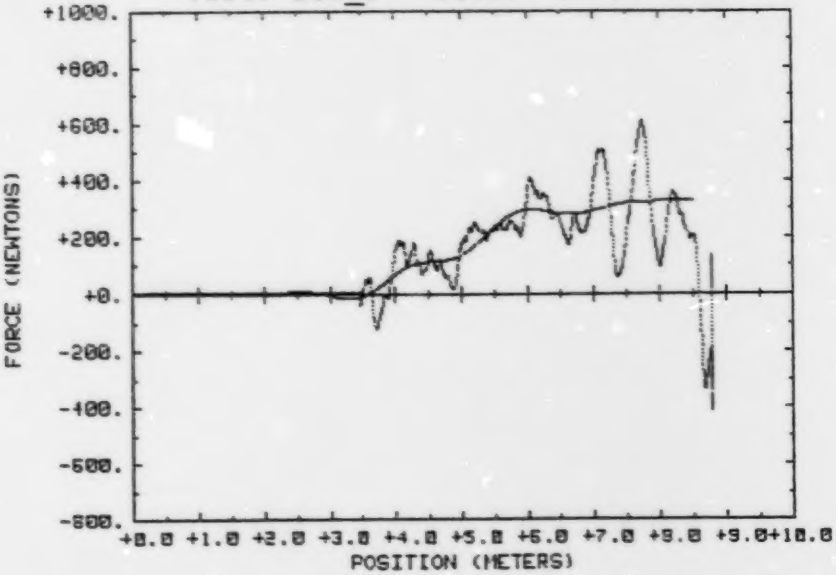

RIDGE MODELLING for DS3 2
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
-600
20
25
30
35
40
45
50
55
60
Time (sec)

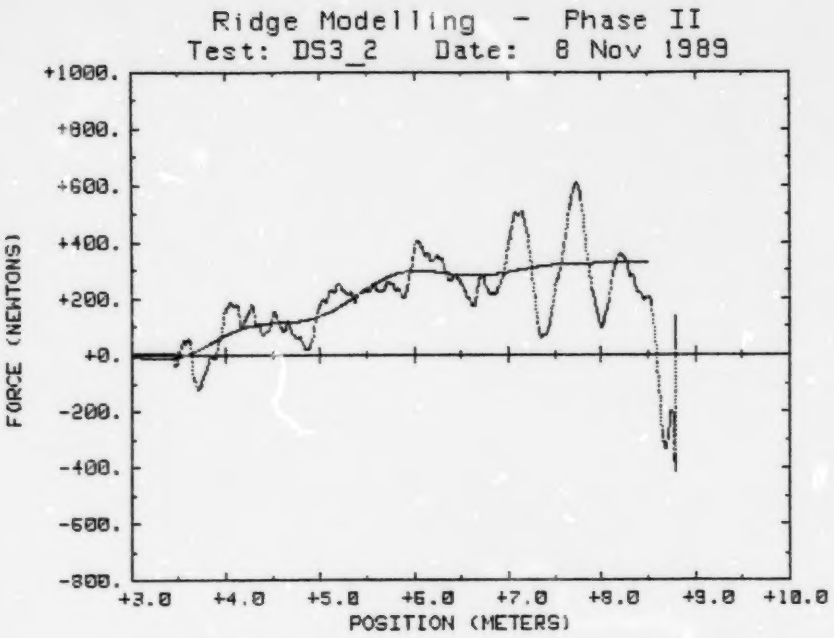

RIDGE MODELLING for DS3 2
POSITION (METERS)
10
8
6
4
2
0
20
25
30
35
40
45
50
55
60
Time (sec)

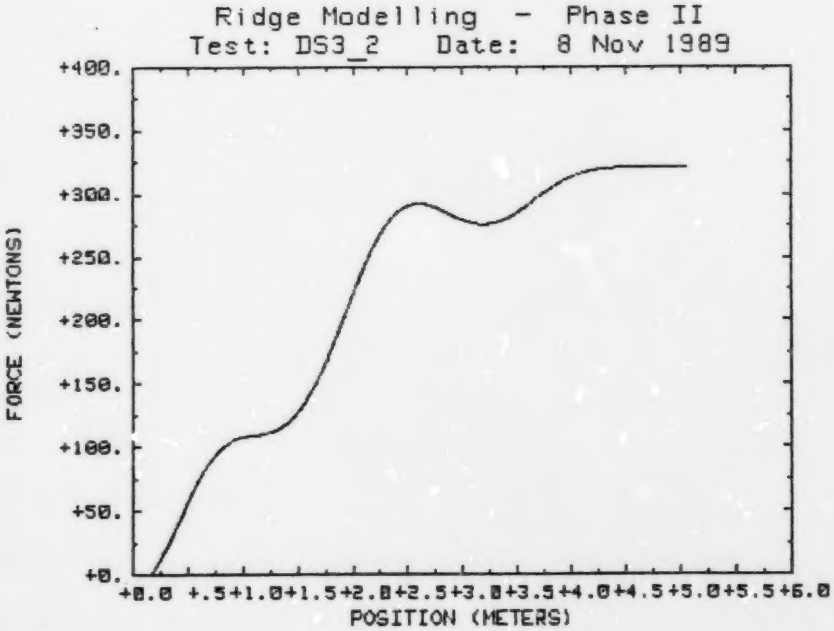
RIDGE MODELLING
Project:3165C Test:DS3_2

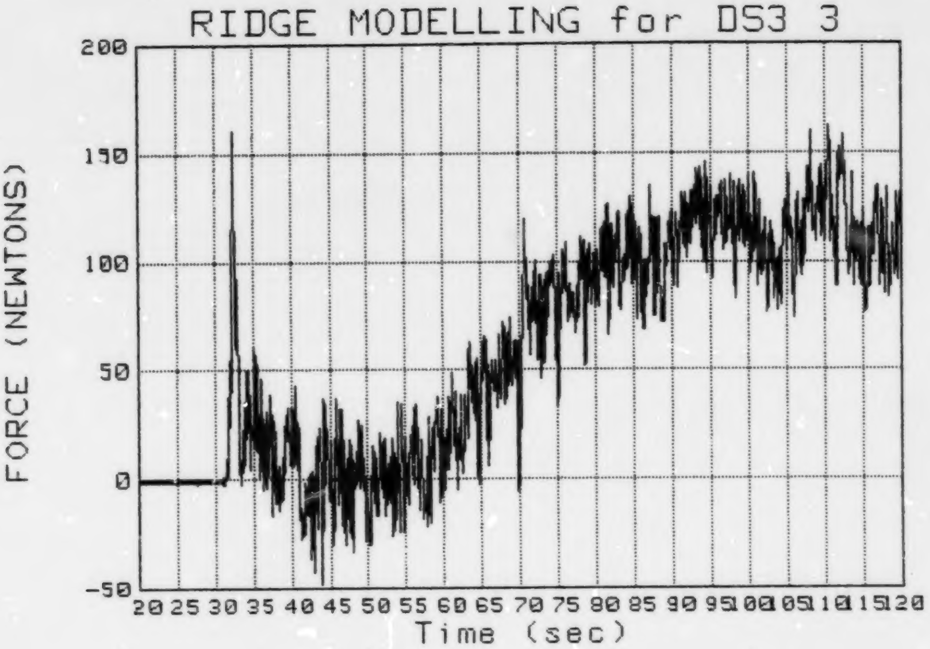


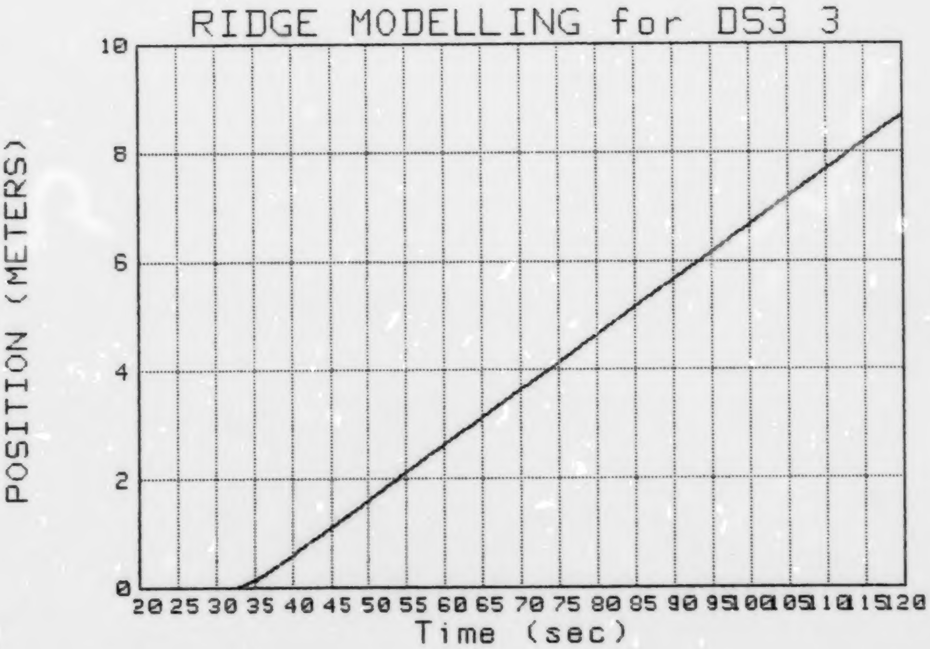
Ridge Modelling - Phase II
Test: DS3_2 Date: 8 Nov 1989

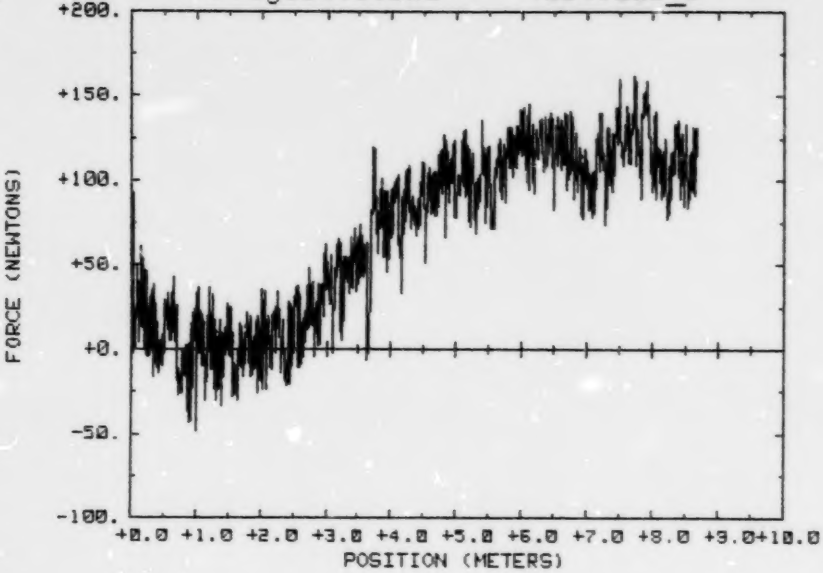



Ridge Modelling - Phase II
Test: DS3_2 Date: 8 Nov 1989
FORCE (NEWTONS)
+1000.
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
-800.
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

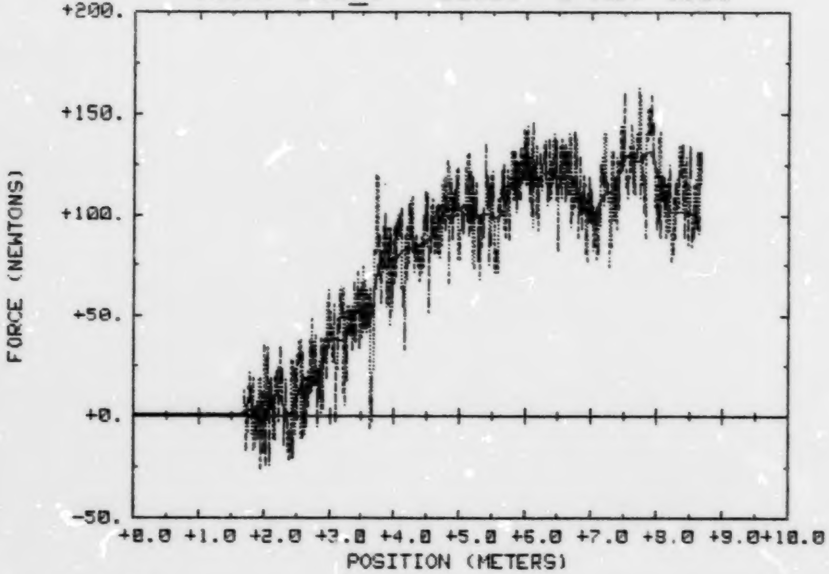

Ridge Modelling - Phase II
Test: DS3_2 Date: 8 Nov 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)


RIDGE MODELLING for DS3 3
FORCE (NEWTONS)
200
150
100
50
0
-50
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Time (sec)

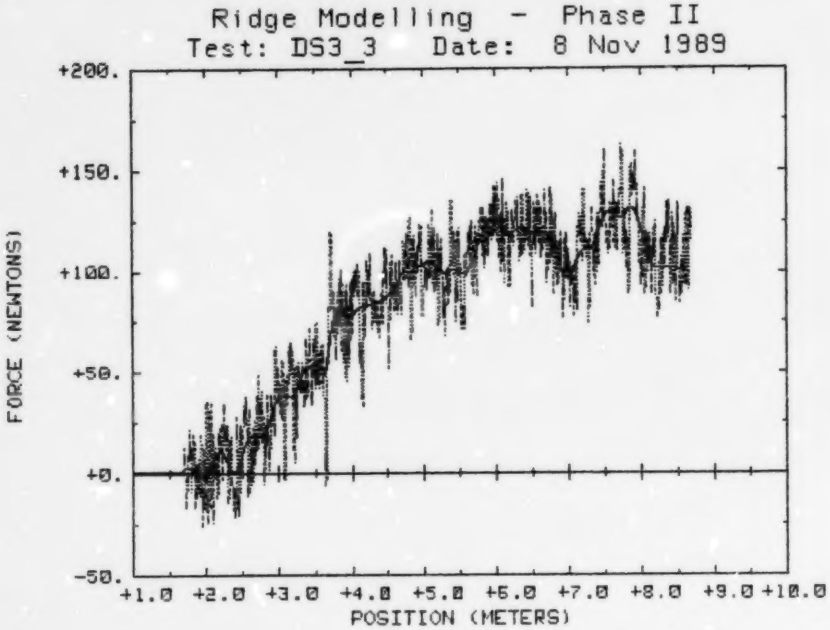

RIDGE MODELLING for DS3 3
POSITION (METERS)
10
8
6
4
2
0
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Time (sec)

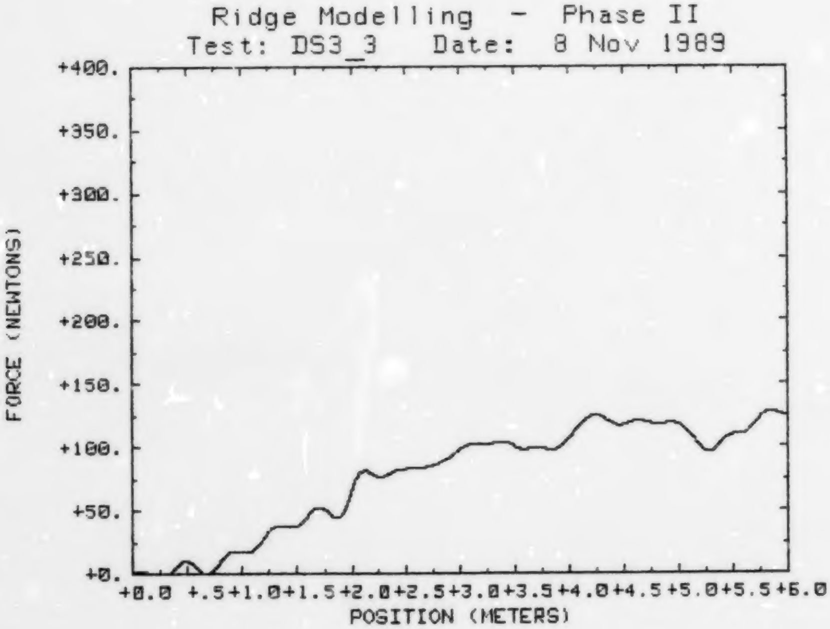


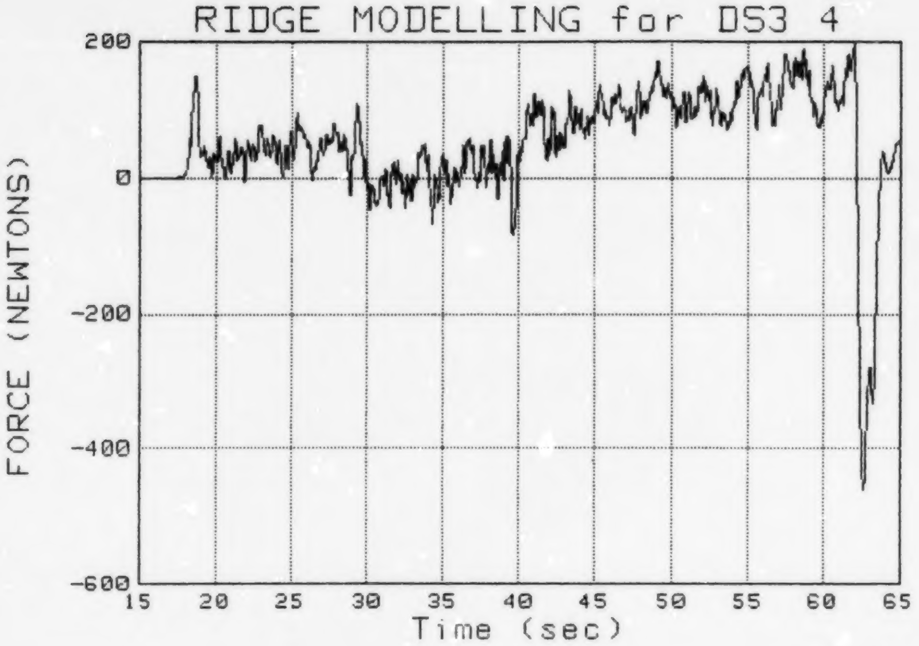
RIDGE MODELLING
Project:3165C Test:DS3_3

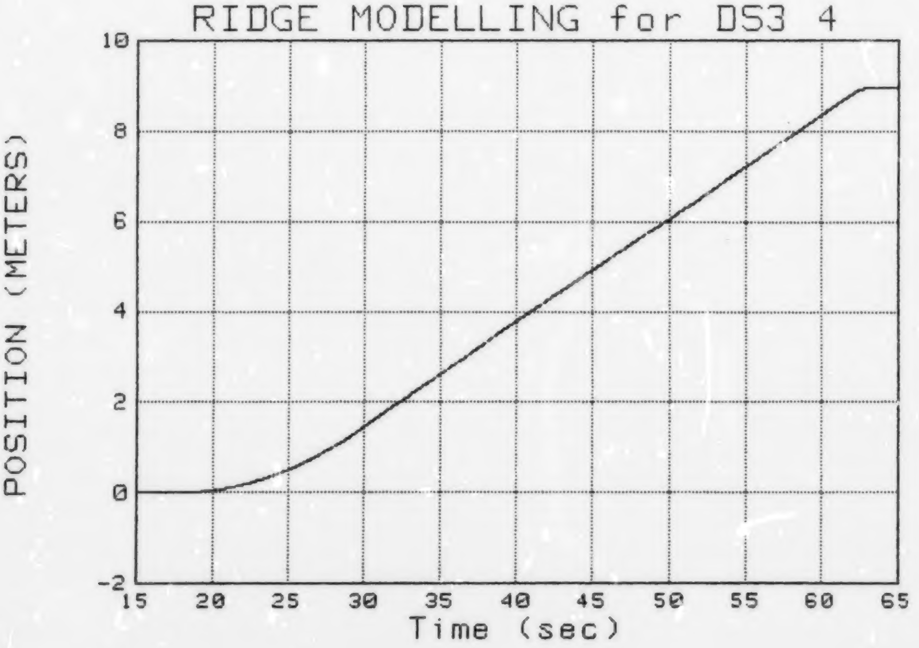


Ridge Modelling - Phase II
Test: DS3_3 Date: 8 Nov 1989

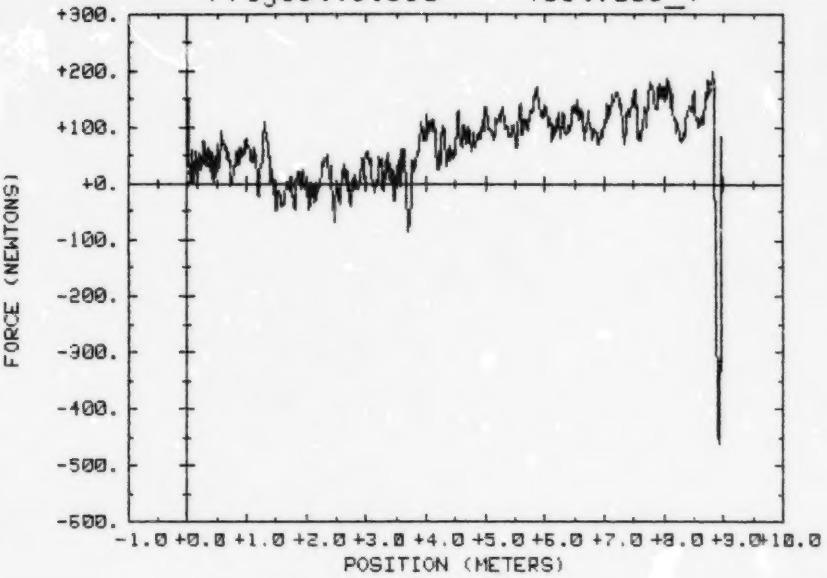

Ridge Modelling - Phase II
Test: DS3_3 Date: 8 Nov 1989
FORCE (NEWTONS)
+200.
+150.
+100.
+50.
+0.
-50.
+1.0
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS3_3 Date: 8 Nov 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

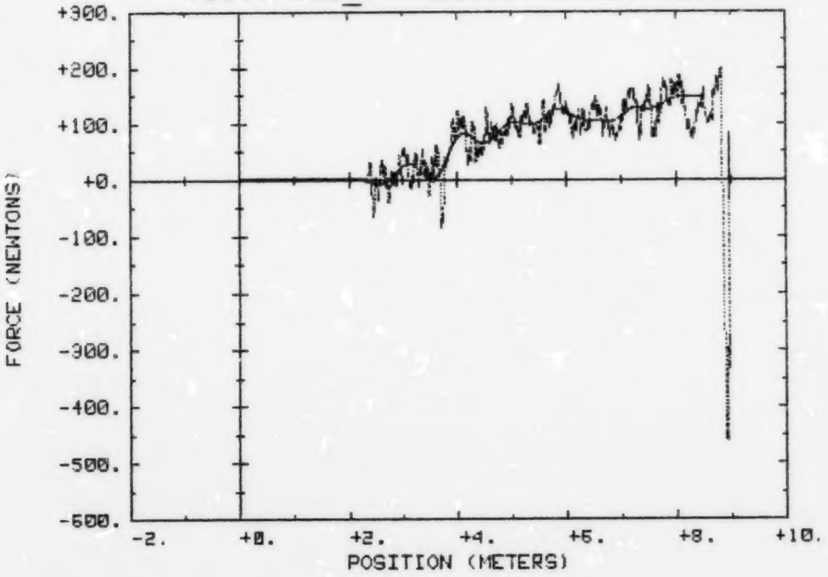

RIDGE MODELLING for DS3 4
FORCE (NEWTONS)
200
0
-200
-400
-600
15
20
25
30
35
40
45
50
55
60
65
Time (sec)

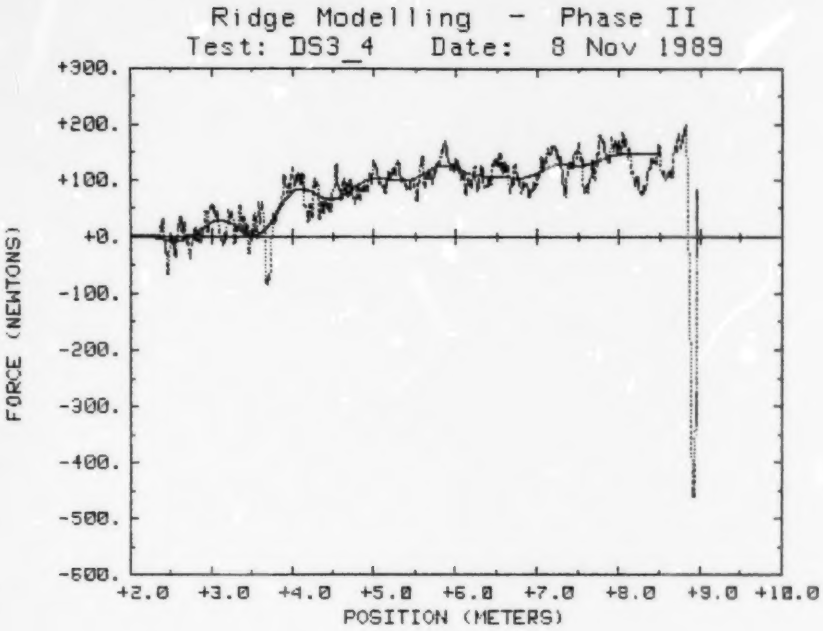

RIDGE MODELLING for DS3 4
POSITION (METERS)
10
8
6
4
2
0
-2
15
20
25
30
35
40
45
50
55
60
65
Time (sec)

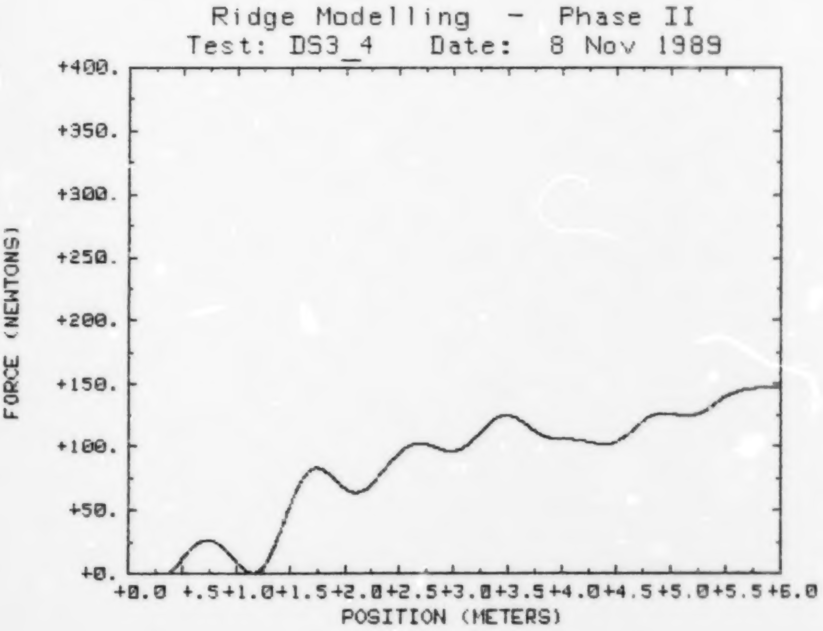
RIDGE MODELLING
Project:3165C Test:DS3_4

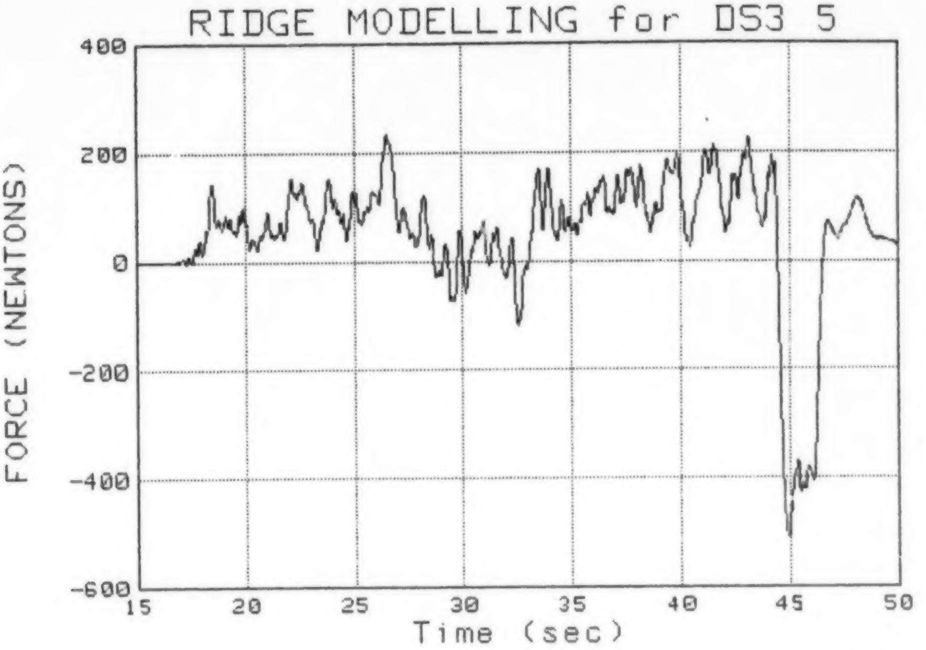


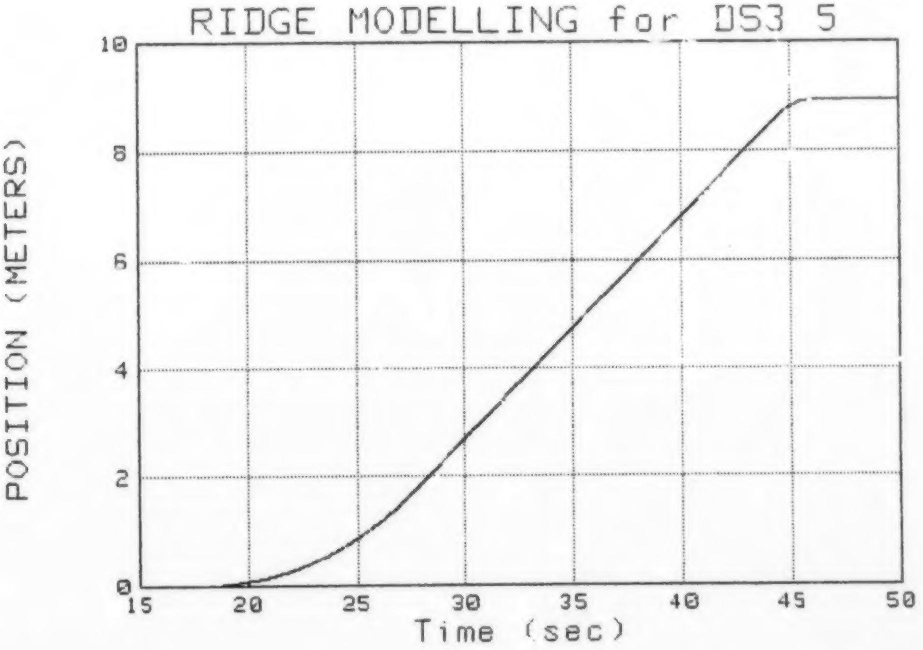
Ridge Modelling - Phase II
Test: DS3_4 Date: 8 Nov 1989

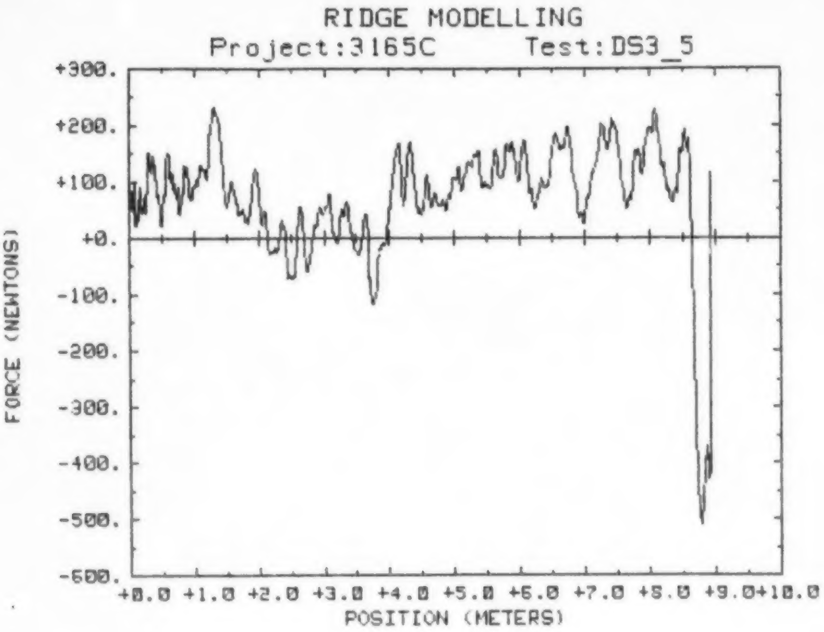


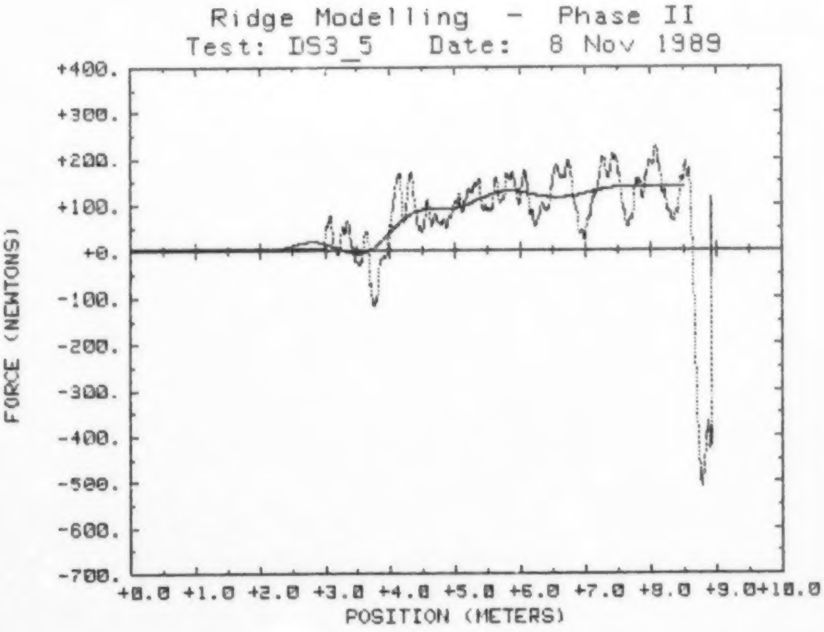

Ridge Modelling - Phase II
Test: DS3_4 Date: 8 Nov 1989

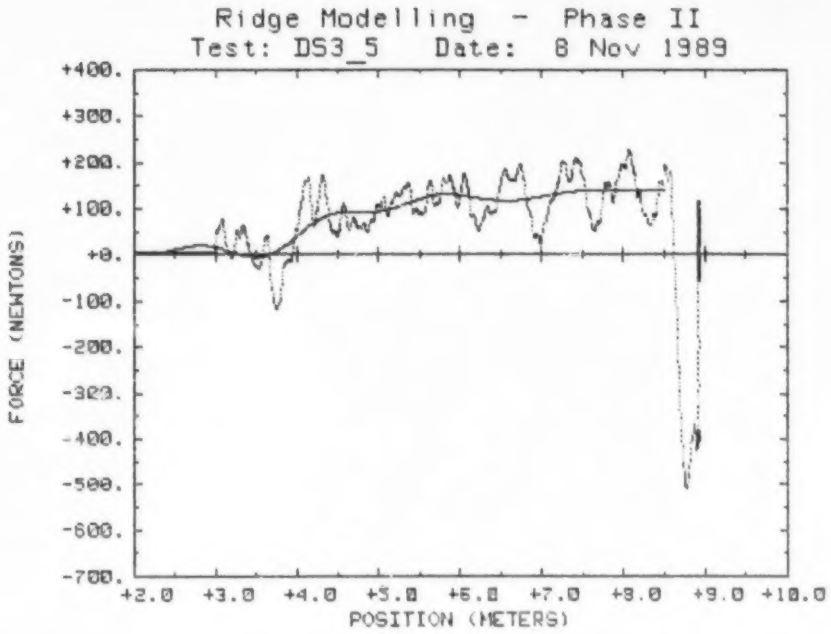

Ridge Modelling - Phase II
Test: DS3_4 Date: 8 Nov 1989

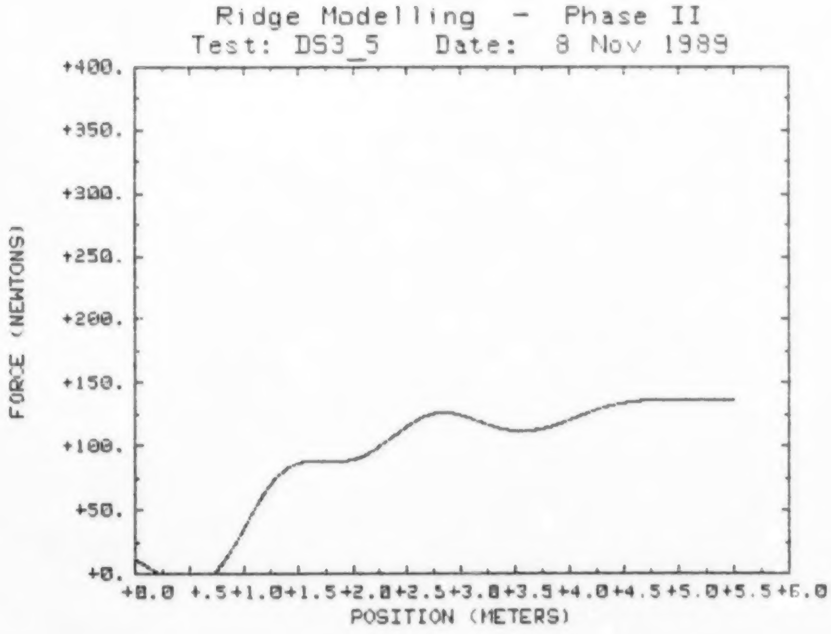

RIDGE MODELLING for DS3 5
FORCE (NEWTONS)
400
200
0
-200
-400
-600
15
20
25
30
35
40
45
50
Time (sec)

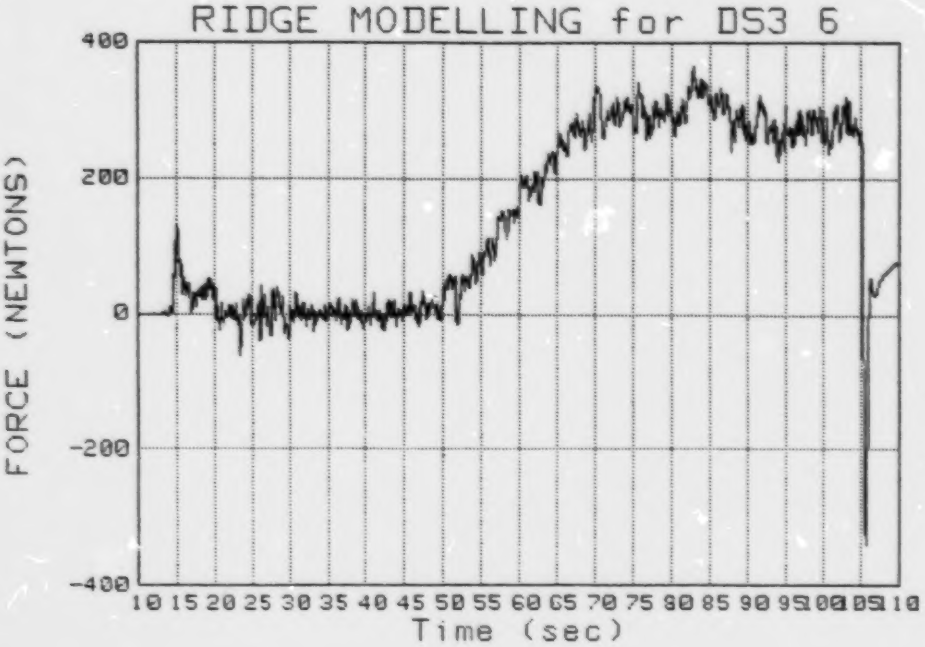

RIDGE MODELLING for DS3 5
POSITION (METERS)
10
8
6
4
2
0
15
20
25
30
35
40
45
50
Time (sec)

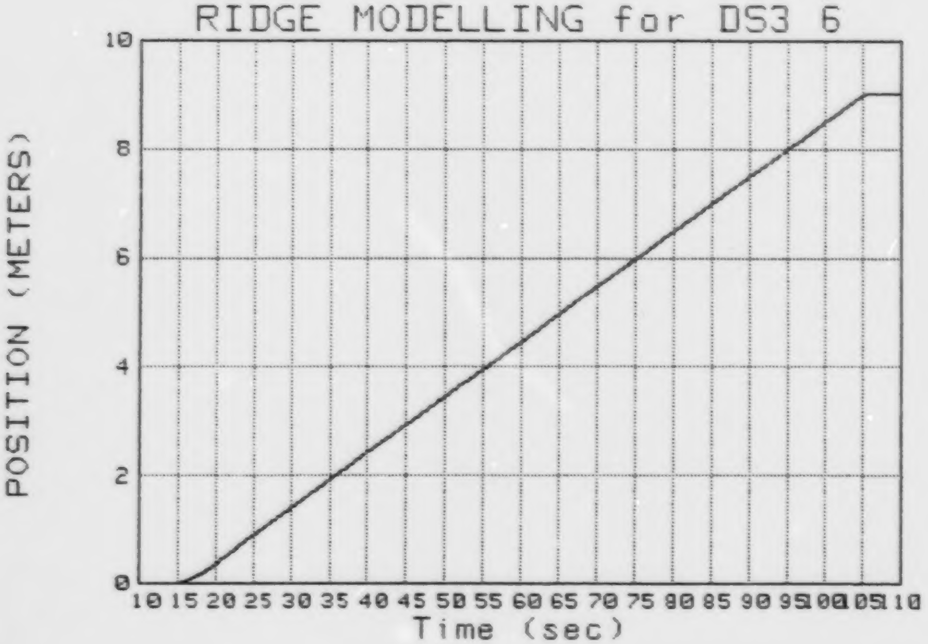

RIDGE MODELLING
Project:3165C Test:DS3_5
FORCE (NEWTONS)
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)

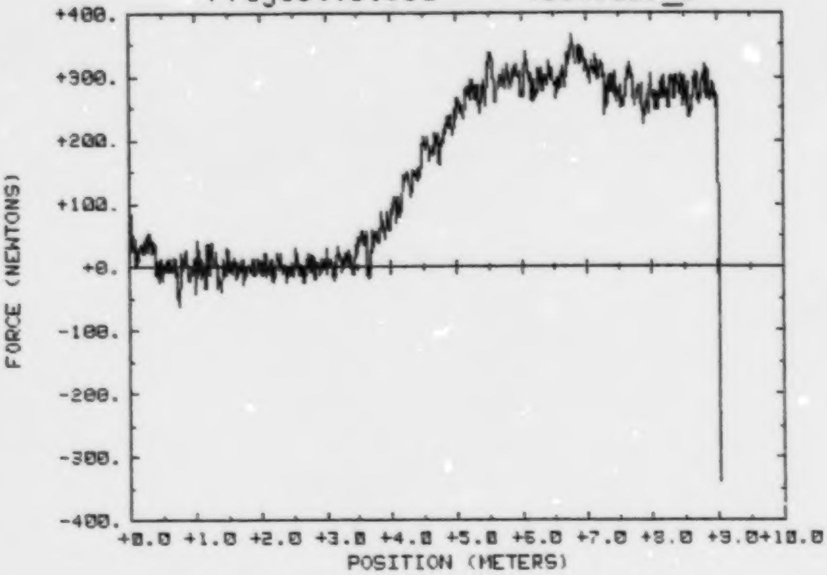

Ridge Modelling - Phase II
Test: DS3_5 Date: 8 Nov 1989
FORCE (NEWTONS)
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
-600.
-700.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0 +10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS3_5 Date: 8 Nov 1989

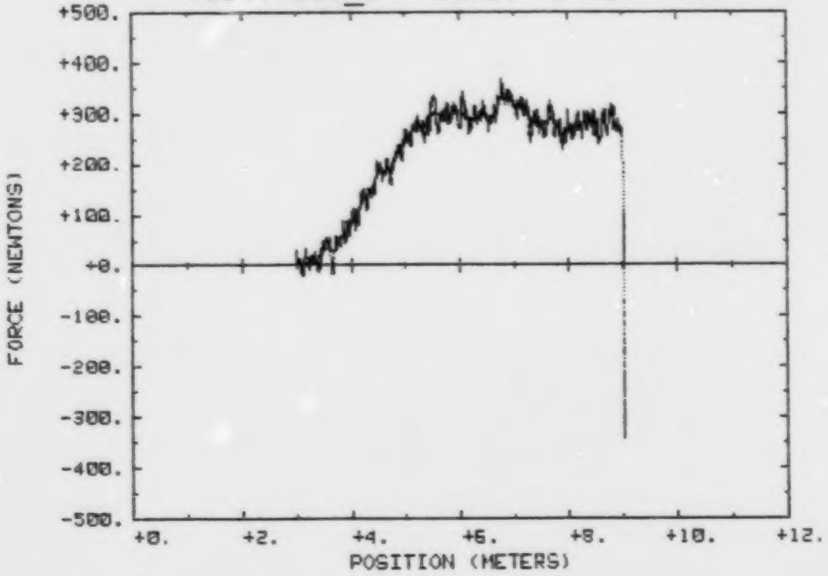

Ridge Modelling - Phase II
Test: DS3_5 Date: 8 Nov 1989


RIDGE MODELLING for DS3 6
400
200
0
-200
-400
FORCE (NEWTONS)
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
Time (sec)

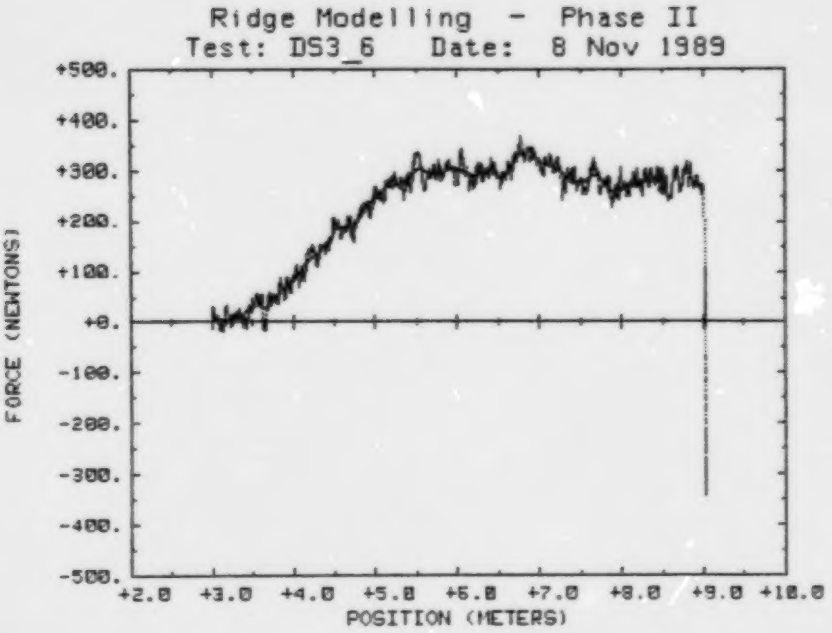

RIDGE MODELLING for DS3 6
10
8
6
4
2
0
POSITION (METERS)
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110
Time (sec)

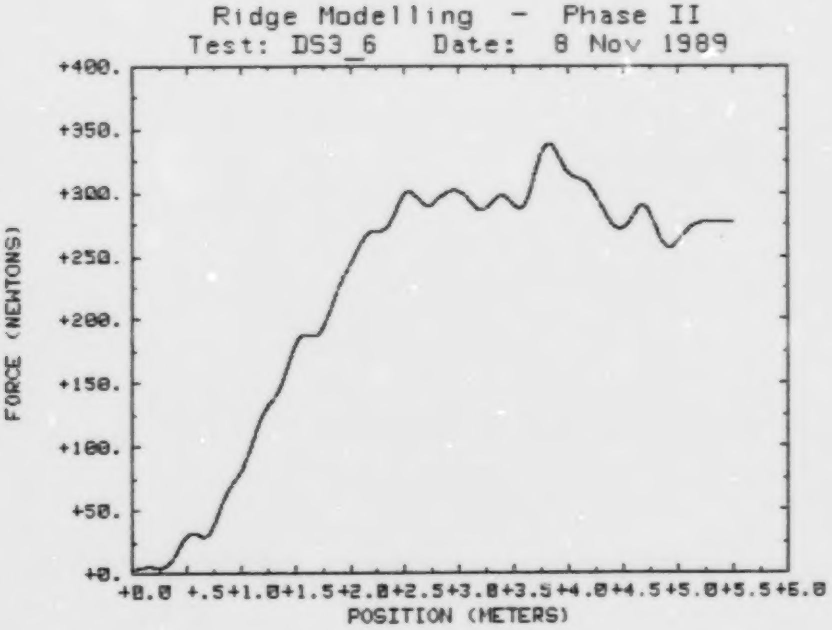


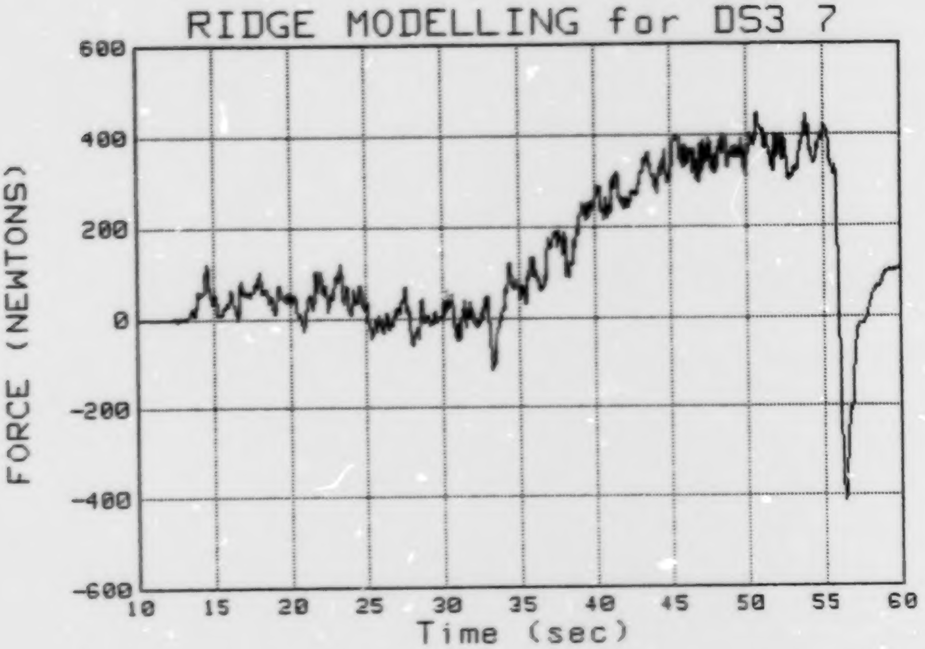
RIDGE MODELLING
Project:3165C Test:DS3_6

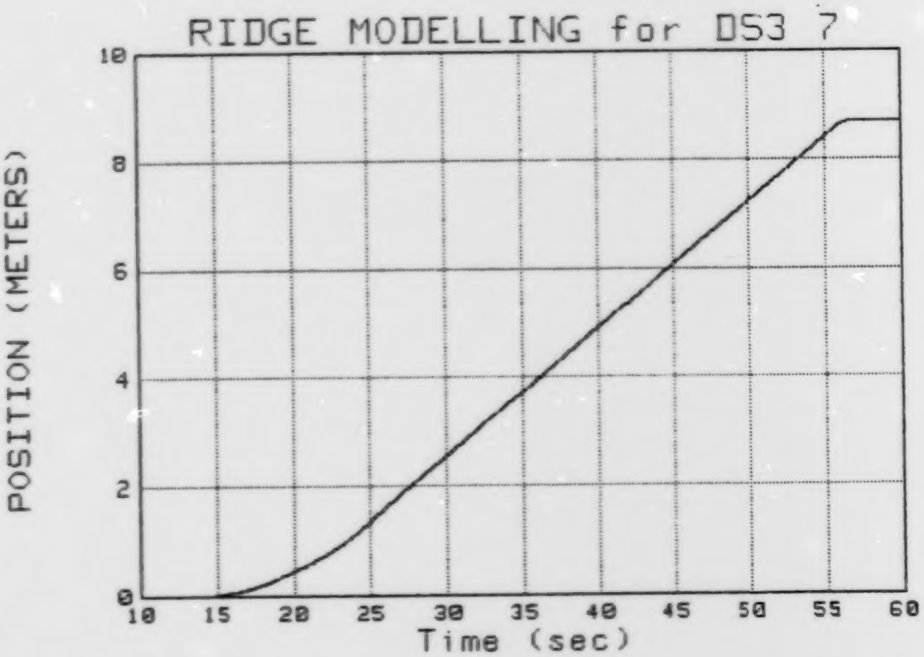


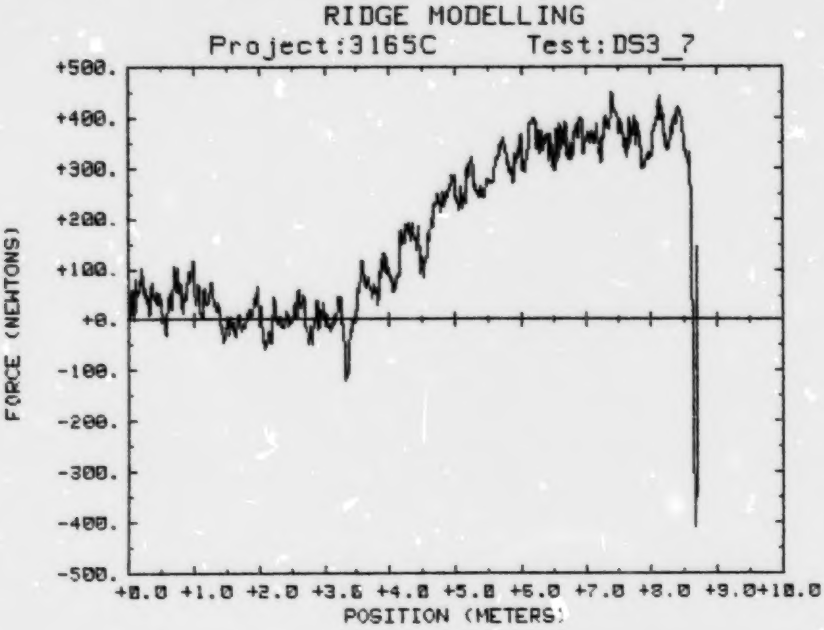
Ridge Modelling - Phase II
Test: DS3_6 Date: 8 Nov 1989

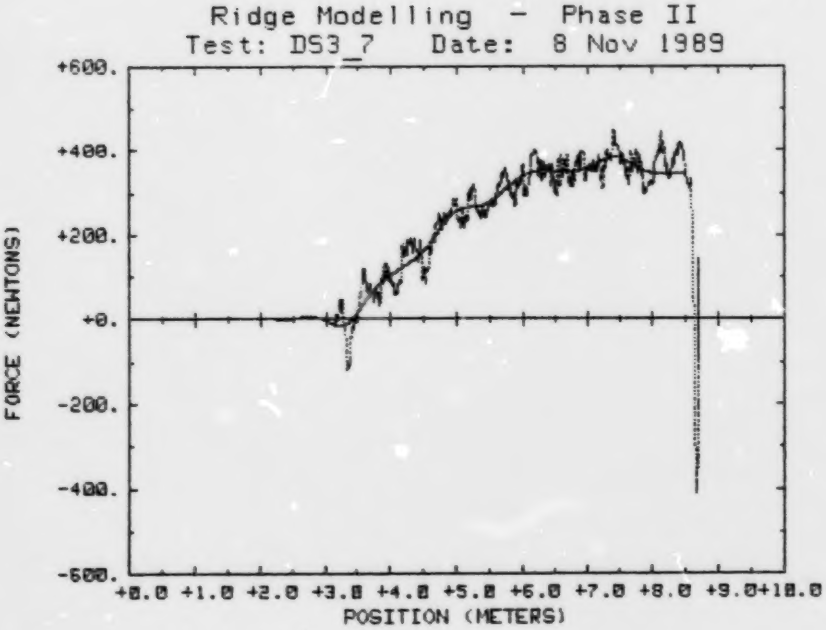

Ridge Modelling - Phase II
Test: DS3_6 Date: 8 Nov 1989
FORCE (NEWTONS)
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
+2.0
+3.0
+4.0
+5.0
+6.0
+7.0
+8.0
+9.0
+10.0
POSITION (METERS)

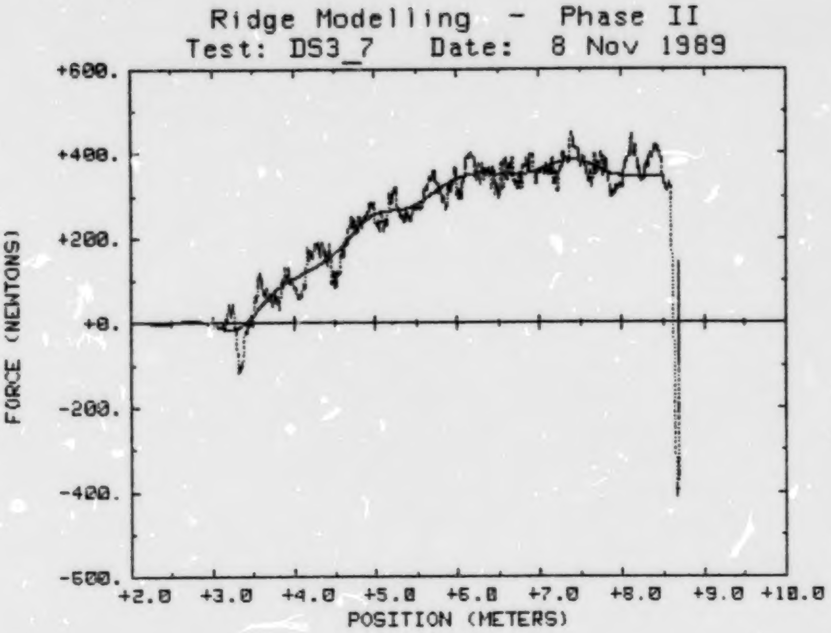

Ridge Modelling - Phase II
Test: DS3_6 Date: 8 Nov 1989
FORCE (NEWTONS)
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
+0.0
+.5
+1.0
+1.5
+2.0
+2.5
+3.0
+3.5
+4.0
+4.5
+5.0
+5.5
+6.0
POSITION (METERS)

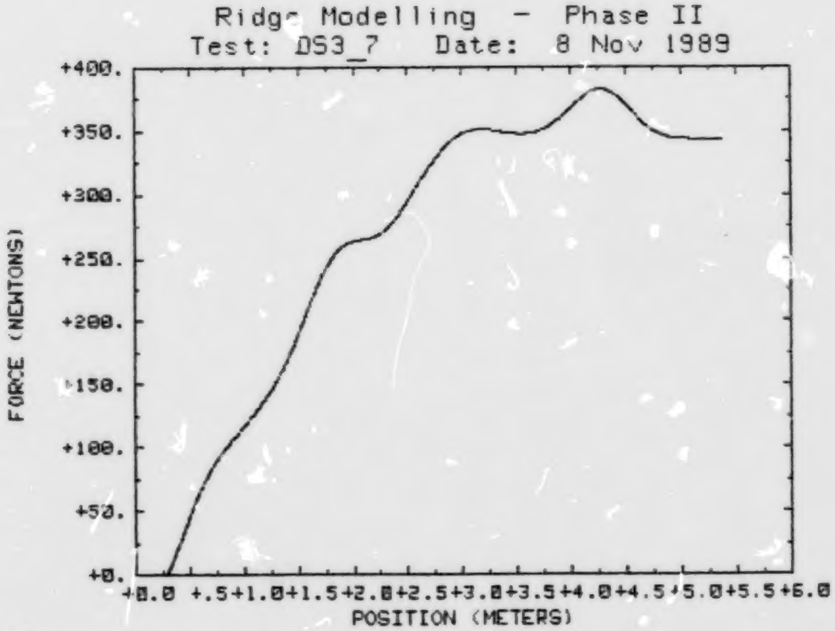

RIDGE MODELLING for DS3 7
FORCE (NEWTONS)
600
400
200
0
-200
-400
-600
10
15
20
25
30
35
40
45
50
55
60
Time (sec)

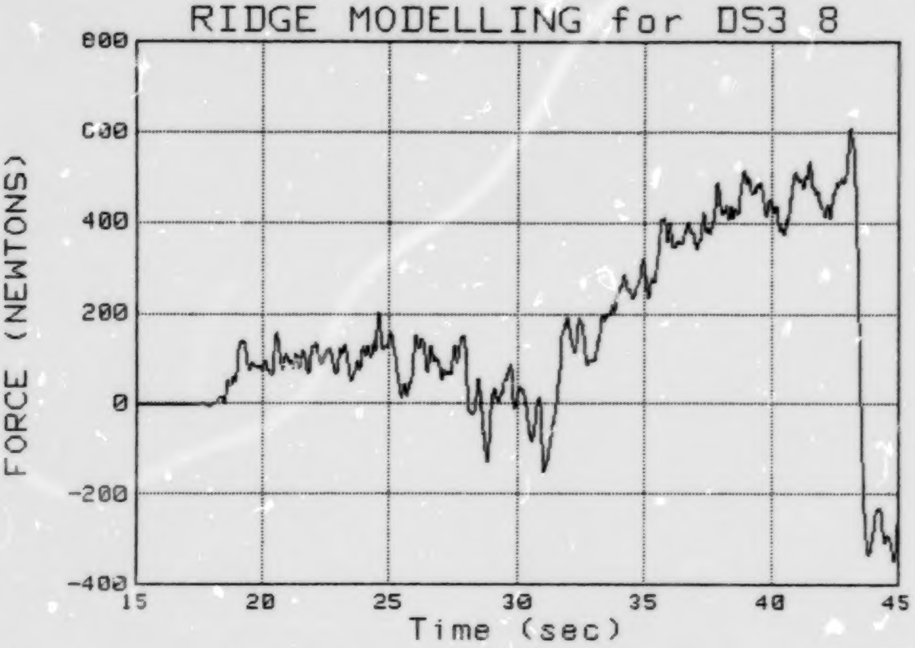

RIDGE MODELLING for DS3 7
POSITION (METERS)
10
8
6
4
2
0
10
15
20
25
30
35
40
45
50
55
60
Time (sec)

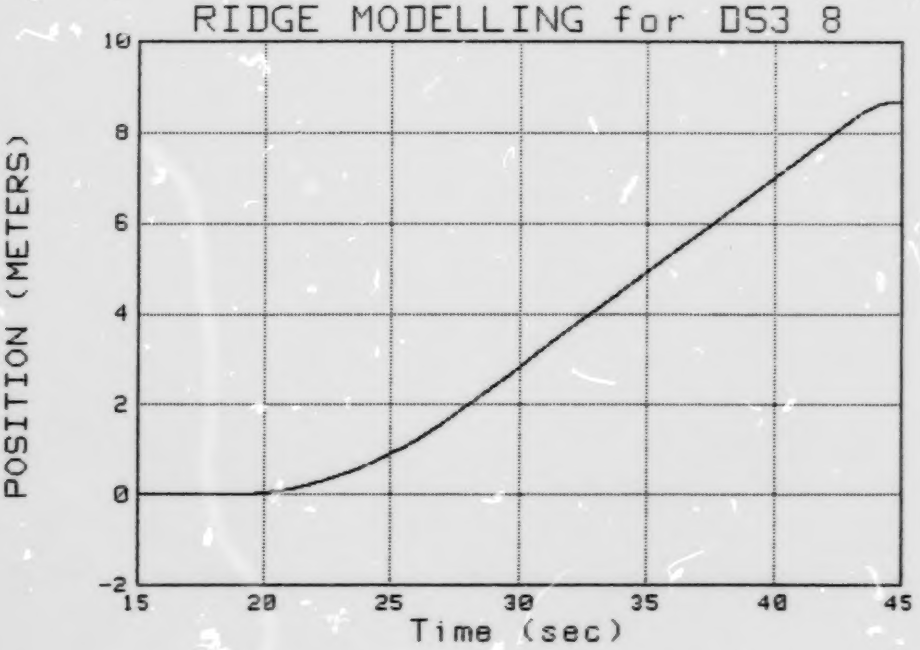

RIDGE MODELLING
Project:3165C Test:DS3_7
FORCE (NEWTONS)
+500.
+400.
+300.
+200.
+100.
+0.
-100.
-200.
-300.
-400.
-500.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS3_7 Date: 8 Nov 1989
FORCE (NEWTONS)
+600.
+400.
+200.
+0.
-200.
-400.
-600.
+0.0 +1.0 +2.0 +3.0 +4.0 +5.0 +6.0 +7.0 +8.0 +9.0+10.0
POSITION (METERS)

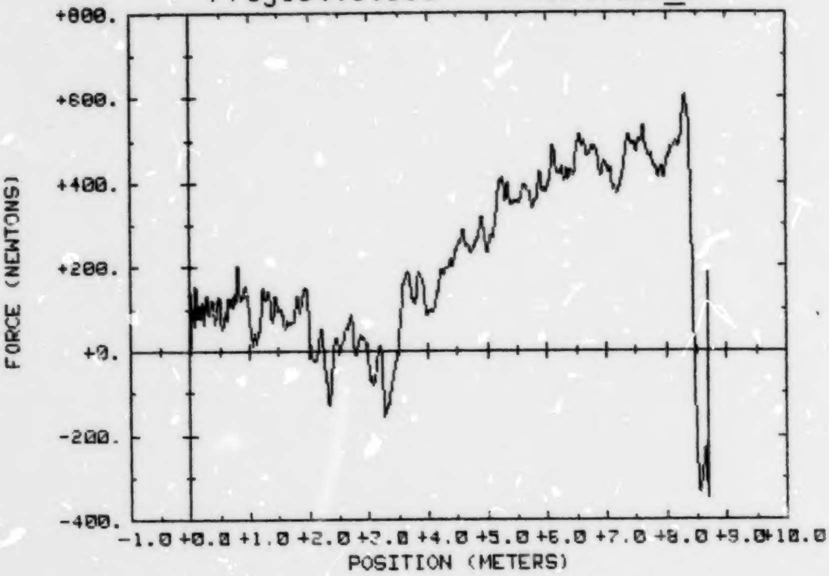

Ridge Modelling - Phase II
Test: DS3_7 Date: 8 Nov 1989


Ridge Modelling - Phase II
Test: DS3_7 Date: 8 Nov 1989

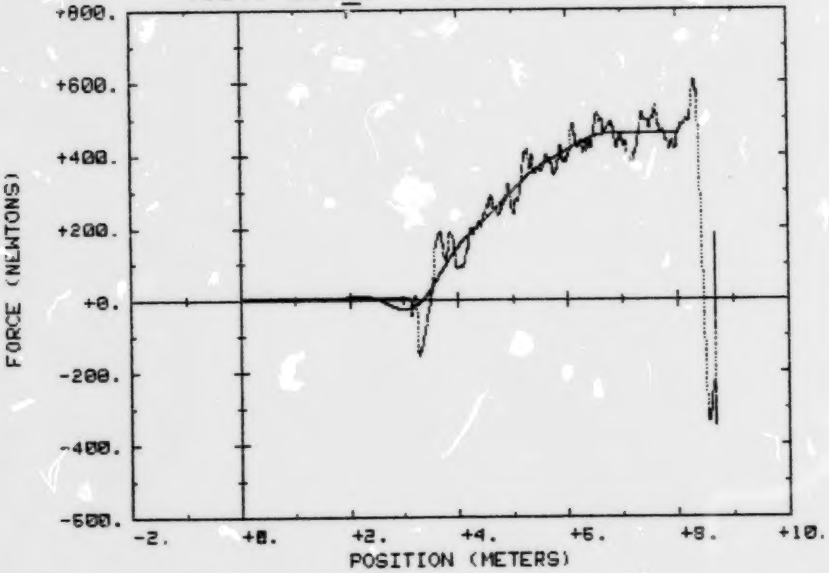

RIDGE MODELLING for DS3 8
FORCE (NEWTONS)
800
600
400
200
0
-200
-400
15
20
25
30
35
40
45
Time (sec)

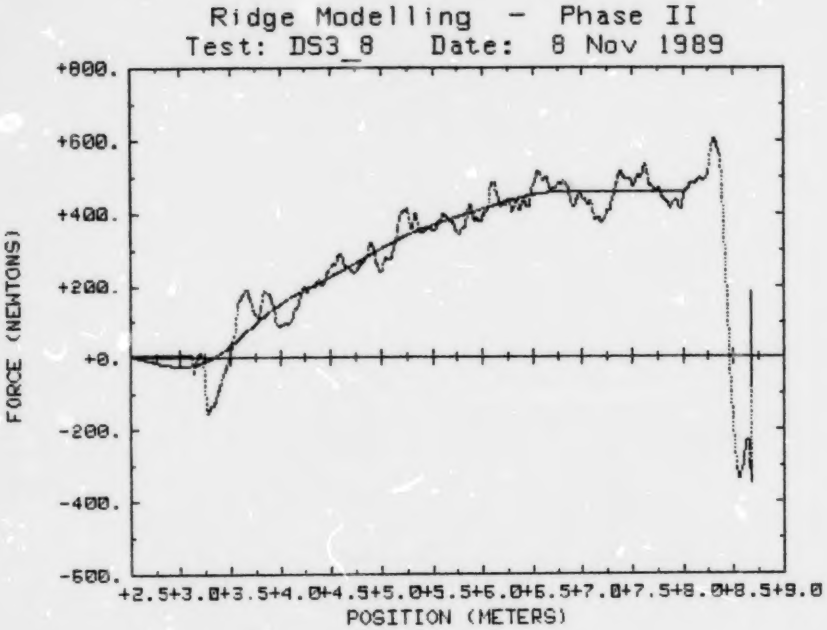

RIDGE MODELLING for DS3 8
POSITION (METERS)
10
8
6
4
2
0
-2
15
20
25
30
35
40
45
Time (sec)

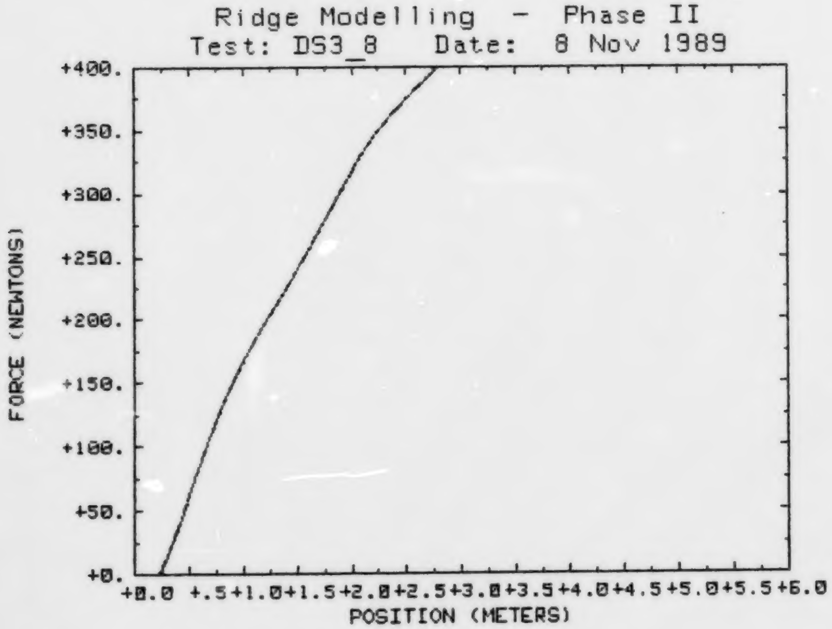
RIDGE MODELLING
Project:3165C Test:DS3_8



Ridge Modelling - Phase II
Test: DS3_8 Date: 8 Nov 1989




Ridge Modelling - Phase II
Test: DS3_8 Date: 8 Nov 1989
+800.
+600.
+400.
+200.
+0.
-200.
-400.
-600.
FORCE (NEWTONS)
+2.5+3.0+3.5+4.0+4.5+5.0+5.5+6.0+6.5+7.0+7.5+8.0+8.5+9.0
POSITION (METERS)


Ridge Modelling - Phase II
Test: DS3_8 Date: 8 Nov 1989
+400.
+350.
+300.
+250.
+200.
+150.
+100.
+50.
+0.
FORCE (NEWTONS)
+0.0 +.5+1.0+1.5+2.0+2.5+3.0+3.5+4.0+4.5+5.0+5.5+6.0
POSITION (METERS)

APPENDIX K

NUMERICAL MODEL RESULTS

Table K-1

POLAR STAR ICEBREAKER

RIDGE 17
Level ice = 0.51 m

28-Jun-90

7	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	25.45 (m)
9	LENGTH	107.3 (m)
10	DISTMAXBEAM	47.3 (m)
11	DISPLACEMENT	11020 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.74 (MN)
14	MAXIMUM THRUST	1.85 (MN)
15	STARTSPEED	4.20 (m/sec)
16	MINSPEED	0.01 (m/sec)
17		
18	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	0.51 (m)
20	RIDGE CONSDEPTH	0.39 (m)
21	RIDGE UNCONSDEPTH	5.30 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL (m)	LEVEL ICE (m)	CONSOLID (m)	UNCONSO (m)
0	0.5	0.5	0.5
20	0.5	0.5	0.5
20	0.5	0.9	5.8
60	0.5	0.9	5.8
60	0.5	0.5	0.5
1133	0.5	0.5	0.5

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	3.6 (-)
CONSTANT C1	0.2 (-)
RUBBLE ICE	
CONSTANT CI	0.20 (-)
CONSTANT alfa	1.24 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12
26 27 28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	4.20	0.98	0.00	0.00	0.00	0.98	0.99	0.00	4.20	4	1	38.48
31	4.20	0.98	0.00	0.00	0.00	0.98	0.99	0.00	4.20	8	2	38.49
32	4.20	0.98	0.00	0.00	0.00	0.98	0.99	0.00	4.20	13	3	38.50
33	4.20	0.98	0.00	0.00	0.00	0.98	0.99	0.00	4.20	17	4	38.50
34	4.20	0.98	0.00	0.00	0.00	0.98	0.99	0.00	4.21	21	5	38.51
35	4.21	0.98	0.00	0.00	0.00	0.98	0.99	0.00	4.21	25	6	38.52
36	4.21	0.98	0.10	0.07	0.30	1.35	0.99	-0.03	4.18	29	7	52.97
37	4.18	0.98	0.10	0.07	0.30	1.34	1.00	-0.03	4.15	34	8	52.75
38	4.15	0.97	0.19	0.13	0.59	1.69	1.00	-0.06	4.09	38	9	66.58
39	4.09	0.96	0.28	0.19	0.89	2.04	1.01	-0.09	4.01	42	10	80.13
40	4.01	0.94	0.37	0.25	1.15	2.35	1.03	-0.11	3.90	46	11	92.25
41	3.90	0.93	0.46	0.30	1.44	2.67	1.05	-0.13	3.76	49	12	104.81
42	3.76	0.90	0.52	0.34	1.65	2.89	1.07	-0.15	3.61	53	13	113.66
43	3.61	0.88	0.52	0.33	1.65	2.86	1.10	-0.15	3.46	56	14	112.19
44	3.46	0.85	0.59	0.36	1.87	3.08	1.12	-0.16	3.30	60	15	121.14
45	3.30	0.82	0.66	0.38	2.07	3.28	1.15	-0.18	3.12	63	16	128.70
46	3.12	0.79	0.72	0.40	2.26	3.45	1.18	-0.19	2.93	66	17	135.64
47	2.93	0.76	0.62	0.33	1.96	3.05	1.22	-0.15	2.78	69	18	119.81
48	2.78	0.73	0.68	0.35	2.16	3.24	1.25	-0.17	2.62	71	19	127.29
49	2.62	0.70	0.59	0.29	1.87	2.86	1.28	-0.13	2.48	74	20	112.25
50	2.48	0.68	0.63	0.30	2.00	2.98	1.30	-0.14	2.34	76	21	117.00
51	2.34	0.65	0.54	0.25	1.71	2.61	1.32	-0.11	2.24	78	22	102.41
52	2.24	0.63	0.58	0.26	1.84	2.73	1.34	-0.12	2.12	80	23	107.38
53	2.12	0.61	0.50	0.21	1.57	2.40	1.36	-0.09	2.04	82	24	94.24
54	2.04	0.60	0.53	0.22	1.68	2.49	1.38	-0.09	1.94	84	25	97.98
55	1.94	0.58	0.44	0.18	1.39	2.15	1.39	-0.06	1.88	86	26	84.47
56	1.88	0.57	0.44	0.17	1.39	2.13	1.41	-0.06	1.82	88	27	83.89
57	1.82	0.56	0.47	0.18	1.47	2.21	1.42	-0.07	1.75	90	28	86.81
58	1.75	0.55	0.40	0.15	1.26	1.95	1.43	-0.04	1.71	91	29	76.80
59	1.71	0.54	0.42	0.16	1.33	2.02	1.44	-0.05	1.66	93	30	79.53
60	1.66	0.53	0.35	0.13	1.11	1.77	1.44	-0.03	1.63	95	31	69.38
61	1.63	0.53	0.35	0.13	1.11	1.76	1.45	-0.03	1.61	96	32	69.15
62	1.61	0.52	0.37	0.13	1.15	1.81	1.45	-0.03	1.58	98	33	70.99
63	1.58	0.52	0.30	0.11	0.96	1.58	1.46	-0.01	1.57	100	34	62.10
64	1.57	0.52	0.30	0.11	0.96	1.58	1.46	-0.01	1.56	101	35	62.01
65	1.56	0.51	0.32	0.11	1.00	1.62	1.46	-0.01	1.55	103	36	63.66
66	1.55	0.51	0.26	0.09	0.81	1.41	1.47	0.00	1.55	104	37	55.27
67	1.55	0.51	0.26	0.09	0.81	1.41	1.46	0.00	1.56	106	38	55.31
68	1.56	0.51	0.27	0.09	0.84	1.44	1.46	0.00	1.56	107	39	56.72
69	1.56	0.51	0.27	0.09	0.84	1.44	1.46	0.00	1.56	109	40	56.74
70	1.56	0.51	0.20	0.07	0.64	1.22	1.46	0.02	1.58	110	41	48.12
71	1.58	0.52	0.21	0.07	0.67	1.26	1.46	0.02	1.59	112	42	49.66
72	1.59	0.52	0.21	0.08	0.67	1.27	1.46	0.02	1.61	114	43	49.80
73	1.61	0.52	0.17	0.06	0.54	1.12	1.45	0.03	1.64	115	44	44.04
74	1.64	0.53	0.18	0.06	0.57	1.16	1.45	0.02	1.66	117	45	45.65
75	1.66	0.53	0.14	0.05	0.43	1.02	1.44	0.04	1.70	119	46	39.94
76	1.70	0.54	0.14	0.05	0.43	1.02	1.44	0.03	1.73	120	47	40.22
77	1.73	0.54	0.14	0.05	0.43	1.03	1.43	0.03	1.77	122	48	40.48
78	1.77	0.55	0.11	0.04	0.33	0.92	1.43	0.04	1.81	124	49	36.22
79	1.81	0.56	0.11	0.04	0.33	0.93	1.42	0.04	1.85	126	50	36.53
80	1.85	0.56	0.11	0.04	0.33	0.94	1.41	0.04	1.89	128	51	36.84

Table K-1 (Cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12
81	1.89	0.57	0.08	0.03	0.25	0.86	1.40	0.05	1.93	130	52	33.64
82	1.93	0.58	0.08	0.03	0.25	0.86	1.40	0.04	1.98	132	53	33.97
83	1.98	0.59	0.06	0.02	0.18	0.79	1.39	0.05	2.03	134	54	31.14
84	2.03	0.60	0.06	0.02	0.18	0.80	1.38	0.05	2.08	136	55	31.50
85	2.08	0.60	0.06	0.02	0.18	0.81	1.37	0.05	2.12	138	56	31.85
86	2.12	0.61	0.04	0.02	0.13	0.77	1.36	0.05	2.17	140	57	30.07
87	2.17	0.62	0.04	0.02	0.13	0.77	1.35	0.05	2.22	142	58	30.43
88	2.22	0.63	0.03	0.01	0.09	0.74	1.35	0.05	2.27	144	59	29.00
89	2.27	0.64	0.03	0.01	0.09	0.75	1.34	0.05	2.32	147	60	29.36
90	2.32	0.65	0.02	0.01	0.06	0.72	1.33	0.05	2.37	149	61	28.29
91	2.37	0.66	0.02	0.01	0.06	0.73	1.32	0.05	2.42	152	62	28.64
92	2.42	0.67	0.01	0.00	0.03	0.70	1.31	0.05	2.47	154	63	27.56
93	2.47	0.67	0.01	0.00	0.03	0.71	1.30	0.05	2.52	157	64	27.92
94	2.52	0.68	0.00	0.00	0.00	0.68	1.29	0.05	2.57	159	65	26.83
95	2.57	0.69	0.00	0.00	0.00	0.69	1.28	0.05	2.62	162	66	27.18
96	2.62	0.70	0.00	0.00	0.00	0.70	1.27	0.05	2.67	164	67	27.52
97	2.67	0.71	0.00	0.00	0.00	0.71	1.27	0.05	2.71	167	68	27.85
98	2.71	0.72	0.00	0.00	0.00	0.72	1.26	0.05	2.76	170	69	28.18
99	2.76	0.73	0.00	0.00	0.00	0.73	1.25	0.04	2.80	173	70	28.49
100	2.80	0.73	0.00	0.00	0.00	0.73	1.24	0.04	2.84	176	71	28.79
101	2.84	0.74	0.00	0.00	0.00	0.74	1.23	0.04	2.89	178	72	29.08
102	2.89	0.75	0.00	0.00	0.00	0.75	1.23	0.04	2.93	181	73	29.37
103	2.93	0.75	0.00	0.00	0.00	0.75	1.22	0.04	2.96	184	74	29.65
104	2.96	0.76	0.00	0.00	0.00	0.76	1.21	0.04	3.00	187	75	29.91
105	3.00	0.77	0.00	0.00	0.00	0.77	1.21	0.04	3.04	190	76	30.18
106	3.04	0.77	0.00	0.00	0.00	0.77	1.20	0.04	3.07	193	77	30.43
107	3.07	0.78	0.00	0.00	0.00	0.78	1.19	0.03	3.11	197	78	30.67
108	3.11	0.79	0.00	0.00	0.00	0.79	1.19	0.03	3.14	200	79	30.91
109	3.14	0.79	0.00	0.00	0.00	0.79	1.18	0.03	3.17	203	80	31.14
110	3.17	0.80	0.00	0.00	0.00	0.80	1.18	0.03	3.21	206	81	31.37
111	3.21	0.80	0.00	0.00	0.00	0.80	1.17	0.03	3.24	209	82	31.59
112	3.24	0.81	0.00	0.00	0.00	0.81	1.16	0.03	3.27	213	83	31.80
113	3.27	0.81	0.00	0.00	0.00	0.81	1.16	0.03	3.29	216	84	32.00
114	3.29	0.82	0.00	0.00	0.00	0.82	1.15	0.03	3.32	219	85	32.20
115	3.32	0.82	0.00	0.00	0.00	0.82	1.15	0.03	3.35	223	86	32.39
116	3.35	0.83	0.00	0.00	0.00	0.83	1.14	0.03	3.38	226	87	32.58
117	3.38	0.83	0.00	0.00	0.00	0.83	1.14	0.03	3.40	229	88	32.76
118	3.40	0.84	0.00	0.00	0.00	0.84	1.14	0.02	3.43	233	89	32.94
119	3.43	0.84	0.00	0.00	0.00	0.84	1.13	0.02	3.45	236	90	33.11
120	3.45	0.85	0.00	0.00	0.00	0.85	1.13	0.02	3.47	240	91	33.28
121	3.47	0.85	0.00	0.00	0.00	0.85	1.12	0.02	3.50	243	92	33.44
122	3.50	0.86	0.00	0.00	0.00	0.86	1.12	0.02	3.52	247	93	33.60
123	3.52	0.86	0.00	0.00	0.00	0.86	1.11	0.02	3.54	250	94	33.75
124	3.54	0.86	0.00	0.00	0.00	0.86	1.11	0.02	3.56	254	95	33.90
125	3.56	0.87	0.00	0.00	0.00	0.87	1.11	0.02	3.58	257	96	34.04
126	3.58	0.87	0.00	0.00	0.00	0.87	1.10	0.02	3.60	261	97	34.18
127	3.60	0.87	0.00	0.00	0.00	0.87	1.10	0.02	3.62	265	98	34.31
128	3.62	0.88	0.00	0.00	0.00	0.88	1.10	0.02	3.64	268	99	34.45
129	3.64	0.88	0.00	0.00	0.00	0.88	1.09	0.02	3.65	272	100	34.57
130	3.65	0.88	0.00	0.00	0.00	0.88	1.09	0.02	3.67	276	101	34.70
131	3.67	0.89	0.00	0.00	0.00	0.89	1.09	0.02	3.69	279	102	34.82
132	3.69	0.89	0.00	0.00	0.00	0.89	1.08	0.02	3.70	283	103	34.93
133	3.70	0.89	0.00	0.00	0.00	0.89	1.08	0.02	3.72	287	104	35.04
134	3.72	0.89	0.00	0.00	0.00	0.89	1.08	0.02	3.74	290	105	35.15
135	3.74	0.90	0.00	0.00	0.00	0.90	1.08	0.01	3.75	294	106	35.26
136	3.75	0.90	0.00	0.00	0.00	0.90	1.07	0.01	3.76	298	107	35.36
137	3.76	0.90	0.00	0.00	0.00	0.90	1.07	0.01	3.78	302	108	35.46
138	3.78	0.91	0.00	0.00	0.00	0.91	1.07	0.01	3.79	305	109	35.56
139	3.79	0.91	0.00	0.00	0.00	0.91	1.07	0.01	3.81	309	110	35.65
140	3.81	0.91	0.00	0.00	0.00	0.91	1.06	0.01	3.82	313	111	35.75
141	3.82	0.91	0.00	0.00	0.00	0.91	1.06	0.01	3.83	317	112	35.83
142	3.83	0.91	0.00	0.00	0.00	0.91	1.06	0.01	3.84	321	113	35.92
143	3.84	0.92	0.00	0.00	0.00	0.92	1.06	0.01	3.85	325	114	36.00
144	3.85	0.92	0.00	0.00	0.00	0.92	1.05	0.01	3.87	328	115	36.09
145	3.87	0.92	0.00	0.00	0.00	0.92	1.05	0.01	3.88	332	116	36.16
146	3.88	0.92	0.00	0.00	0.00	0.92	1.05	0.01	3.89	336	117	36.24
147	3.89	0.92	0.00	0.00	0.00	0.92	1.05	0.01	3.90	340	118	36.32
148	3.90	0.93	0.00	0.00	0.00	0.93	1.05	0.01	3.91	344	119	36.39
149	3.91	0.93	0.00	0.00	0.00	0.93	1.05	0.01	3.92	348	120	36.46
150	3.92	0.93	0.00	0.00	0.00	0.93	1.04	0.01	3.93	352	121	36.52
151	3.93	0.93	0.00	0.00	0.00	0.93	1.04	0.01	3.94	356	122	36.59
152	3.94	0.93	0.00	0.00	0.00	0.93	1.04	0.01	3.95	360	123	36.65
153	3.95	0.93	0.00	0.00	0.00	0.93	1.04	0.01	3.95	364	124	36.72
154	3.95	0.94	0.00	0.00	0.00	0.94	1.04	0.01	3.96	368	125	36.78
155	3.96	0.94	0.00	0.00	0.00	0.94	1.04	0.01	3.97	372	126	36.83
156	3.97	0.94	0.00	0.00	0.00	0.94	1.03	0.01	3.98	376	127	36.89
157	3.98	0.94	0.00	0.00	0.00	0.94	1.03	0.01	3.99	380	128	36.95
158	3.99	0.94	0.00	0.00	0.00	0.94	1.03	0.01	3.99	384	129	37.00
159	3.99	0.94	0.00	0.00	0.00	0.94	1.03	0.01	4.00	388	130	37.05
160	4.00	0.94	0.00	0.00	0.00	0.94	1.03	0.01	4.01	392	131	37.10

Table K-2

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

POLAR STAR ICEBREAKER

RIDGE 18
Level ice = 0.46 m

28-Jun-90

INPUT OF SHIP CHARACTERISTICS	
BEAM	25.45 (m)
LENGTH	107.3 (m)
DISTMAXBEAM	47.3 (m)
DISPLACEMENT	11020 (Tons)
ADDED MASS	1.09 (-)
BOLLARD THRUST	1.85 (MN)
MAXIMUM THRUST	1.85 (MN)
STARTSPEED	5.75 (m/sec)
MINSPEED	0.01 (m/sec)

INPUT OF DESIRED ICE VARIABLES	
ICE THICKNESS	0.46 (m)
RIDGE CONSDEPTH	1.10 (m)
RIDGE UNCONSDEPTH	3.70 (m)
RIDGE WIDTH	40.00 (m)
DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL (m)	LEVEL ICE (m)	CONSOLID (m)	UNCONSO (m)
0	0.5	0.5	0.5
20	0.5	0.5	0.5
20	0.5	1.6	4.2
60	0.5	1.6	4.2
60	0.5	0.5	0.5
1133	0.5	0.5	0.5

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	3.6 (-)
CONSTANT C1	0.2 (-)
RUBBLE ICE	
CONSTANT Cl	0.20 (-)
CONSTANT alfa	1.24 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26-28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	5.75	1.11	0.00	0.00	0.00	1.11	0.76	-0.03	5.72	6	1	43.57
31	5.72	1.10	0.00	0.00	0.00	1.10	0.77	-0.03	5.69	11	2	43.39
32	5.69	1.10	0.00	0.00	0.00	1.10	0.77	-0.03	5.67	17	3	43.21
33	5.67	1.10	0.00	0.00	0.00	1.10	0.78	-0.03	5.64	23	4	43.04
34	5.64	1.09	0.00	0.00	0.00	1.09	0.78	-0.03	5.61	28	5	42.88
35	5.61	1.09	0.10	0.31	0.19	1.59	0.79	-0.07	5.55	34	6	62.40
36	5.55	1.08	0.19	0.60	0.38	2.06	0.80	-0.10	5.44	39	7	80.95
37	5.44	1.06	0.37	1.16	0.74	2.96	0.82	-0.18	5.26	45	8	116.31
38	5.26	1.03	0.48	1.42	0.92	3.37	0.86	-0.21	5.06	50	9	132.40
39	5.06	1.00	0.52	1.58	1.06	3.64	0.89	-0.23	4.83	54	10	143.08
40	4.83	0.96	0.59	1.75	1.20	3.91	0.94	-0.25	4.58	59	11	153.54
41	4.58	0.92	0.66	1.87	1.33	4.12	0.98	-0.26	4.32	63	12	161.79
42	4.32	0.88	0.72	1.97	1.45	4.30	1.03	-0.27	4.05	67	13	168.87
43	4.05	0.84	0.68	1.81	1.38	4.03	1.09	-0.25	3.80	71	14	158.29
44	3.80	0.80	0.59	1.51	1.20	3.50	1.13	-0.20	3.60	75	15	137.61
45	3.60	0.77	0.54	1.34	1.09	3.20	1.17	-0.17	3.44	78	16	125.78
46	3.44	0.74	0.58	1.41	1.18	3.33	1.20	-0.18	3.26	82	17	130.78
47	3.26	0.71	0.53	1.24	1.07	3.03	1.23	-0.15	3.11	85	18	119.10
48	3.11	0.69	0.44	1.01	0.89	2.59	1.26	-0.11	3.00	88	19	101.71
49	3.00	0.67	0.47	1.05	0.94	2.66	1.28	-0.11	2.88	91	20	104.49
50	2.88	0.65	0.40	0.88	0.81	2.34	1.31	-0.09	2.80	93	21	91.76
51	2.80	0.64	0.35	0.76	0.71	2.11	1.32	-0.07	2.73	96	22	82.87
52	2.73	0.63	0.37	0.78	0.74	2.15	1.33	-0.07	2.66	99	23	84.58
53	2.66	0.62	0.30	0.64	0.61	1.87	1.35	-0.04	2.62	101	24	73.59
54	2.62	0.61	0.32	0.66	0.64	1.91	1.35	-0.05	2.57	104	25	75.15
55	2.57	0.60	0.26	0.53	0.52	1.65	1.36	-0.02	2.55	106	26	64.94
56	2.55	0.60	0.27	0.55	0.54	1.69	1.37	-0.03	2.52	109	27	66.31
57	2.52	0.60	0.20	0.42	0.41	1.42	1.37	0.00	2.52	111	28	55.98
58	2.52	0.59	0.21	0.44	0.43	1.46	1.37	-0.01	2.51	114	29	57.55
59	2.51	0.59	0.17	0.35	0.34	1.29	1.38	0.01	2.52	117	30	50.65
60	2.52	0.59	0.18	0.37	0.36	1.33	1.37	0.00	2.52	119	31	52.32
61	2.52	0.60	0.14	0.28	0.28	1.16	1.37	0.02	2.54	122	32	45.51
62	2.54	0.60	0.11	0.22	0.21	1.03	1.37	0.03	2.57	124	33	40.42
63	2.57	0.60	0.11	0.22	0.21	1.03	1.36	0.03	2.60	127	34	40.65
64	2.60	0.61	0.08	0.17	0.16	0.94	1.36	0.04	2.63	129	35	36.81
65	2.63	0.61	0.08	0.17	0.16	0.94	1.35	0.03	2.67	132	36	37.07
66	2.67	0.62	0.06	0.12	0.12	0.86	1.35	0.04	2.71	135	37	33.66
67	2.71	0.62	0.06	0.12	0.12	0.86	1.34	0.04	2.75	137	38	33.95
68	2.75	0.63	0.04	0.09	0.09	0.81	1.33	0.04	2.79	140	39	31.77
69	2.79	0.64	0.04	0.09	0.09	0.82	1.32	0.04	2.83	143	40	32.07
70	2.83	0.64	0.03	0.07	0.06	0.77	1.31	0.05	2.88	146	41	30.29
71	2.88	0.65	0.02	0.04	0.04	0.74	1.31	0.05	2.92	149	42	28.93
72	2.92	0.66	0.02	0.04	0.04	0.74	1.30	0.05	2.97	152	43	29.24
73	2.97	0.67	0.01	0.02	0.02	0.71	1.29	0.05	3.02	155	44	27.87
74	3.02	0.67	0.00	0.00	0.00	0.67	1.28	0.05	3.07	158	45	26.49
75	3.07	0.68	0.00	0.00	0.00	0.68	1.27	0.05	3.12	161	46	26.81
76	3.12	0.69	0.00	0.00	0.00	0.69	1.26	0.05	3.17	164	47	27.11
77	3.17	0.70	0.00	0.00	0.00	0.70	1.25	0.05	3.21	167	48	27.41
78	3.21	0.70	0.00	0.00	0.00	0.70	1.24	0.04	3.26	171	49	27.70
79	3.26	0.71	0.00	0.00	0.00	0.71	1.23	0.04	3.30	174	50	27.98
80	3.30	0.72	0.00	0.00	0.00	0.72	1.23	0.04	3.34	177	51	28.25

Table K-2 (Cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12
81	3.34	0.73	0.00	0.00	0.00	0.73	1.22	0.04	3.38	181	52	28.51
82	3.38	0.73	0.00	0.00	0.00	0.73	1.21	0.04	3.42	184	53	28.77
83	3.42	0.74	0.00	0.00	0.00	0.74	1.20	0.04	3.46	188	54	29.02
84	3.46	0.74	0.00	0.00	0.00	0.74	1.20	0.04	3.50	191	55	29.26
85	3.50	0.75	0.00	0.00	0.00	0.75	1.19	0.04	3.54	195	56	29.50
86	3.54	0.76	0.00	0.00	0.00	0.76	1.18	0.04	3.57	198	57	29.72
87	3.57	0.76	0.00	0.00	0.00	0.76	1.18	0.03	3.61	202	58	29.95
88	3.61	0.77	0.00	0.00	0.00	0.77	1.17	0.03	3.64	205	59	30.16
89	3.64	0.77	0.00	0.00	0.00	0.77	1.16	0.03	3.67	209	60	30.37
90	3.67	0.78	0.00	0.00	0.00	0.78	1.16	0.03	3.70	213	61	30.57
91	3.70	0.78	0.00	0.00	0.00	0.78	1.15	0.03	3.73	217	62	30.77
92	3.73	0.79	0.00	0.00	0.00	0.79	1.14	0.03	3.76	220	63	30.96
93	3.76	0.79	0.00	0.00	0.00	0.79	1.14	0.03	3.79	224	64	31.15
94	3.79	0.80	0.00	0.00	0.00	0.80	1.13	0.03	3.82	228	65	31.33
95	3.82	0.80	0.00	0.00	0.00	0.80	1.13	0.03	3.85	232	66	31.50
96	3.85	0.81	0.00	0.00	0.00	0.81	1.12	0.03	3.87	236	67	31.67
97	3.87	0.81	0.00	0.00	0.00	0.81	1.12	0.03	3.90	240	68	31.84
98	3.90	0.81	0.00	0.00	0.00	0.81	1.11	0.02	3.92	244	69	32.00
99	3.92	0.82	0.00	0.00	0.00	0.82	1.11	0.02	3.95	247	70	32.15
100	3.95	0.82	0.00	0.00	0.00	0.82	1.10	0.02	3.97	251	71	32.30
101	3.97	0.83	0.00	0.00	0.00	0.83	1.10	0.02	3.99	255	72	32.45
102	3.99	0.83	0.00	0.00	0.00	0.83	1.10	0.02	4.02	259	73	32.59
103	4.02	0.83	0.00	0.00	0.00	0.83	1.09	0.02	4.04	263	74	32.73
104	4.04	0.84	0.00	0.00	0.00	0.84	1.09	0.02	4.06	268	75	32.86
105	4.06	0.84	0.00	0.00	0.00	0.84	1.08	0.02	4.08	272	76	32.99
106	4.08	0.84	0.00	0.00	0.00	0.84	1.08	0.02	4.10	276	77	33.12
107	4.10	0.85	0.00	0.00	0.00	0.85	1.08	0.02	4.12	280	78	33.24
108	4.12	0.85	0.00	0.00	0.00	0.85	1.07	0.02	4.14	284	79	33.36
109	4.14	0.85	0.00	0.00	0.00	0.85	1.07	0.02	4.15	288	80	33.48
110	4.15	0.85	0.00	0.00	0.00	0.85	1.06	0.02	4.17	292	81	33.59
111	4.17	0.86	0.00	0.00	0.00	0.86	1.06	0.02	4.19	296	82	33.70
112	4.19	0.86	0.00	0.00	0.00	0.86	1.06	0.02	4.21	301	83	33.81
113	4.21	0.86	0.00	0.00	0.00	0.86	1.06	0.02	4.22	305	84	33.91
114	4.22	0.87	0.00	0.00	0.00	0.87	1.05	0.02	4.24	309	85	34.01
115	4.24	0.87	0.00	0.00	0.00	0.87	1.05	0.02	4.25	313	86	34.11
116	4.25	0.87	0.00	0.00	0.00	0.87	1.05	0.01	4.27	318	87	34.20
117	4.27	0.87	0.00	0.00	0.00	0.87	1.04	0.01	4.28	322	88	34.29
118	4.28	0.88	0.00	0.00	0.00	0.88	1.04	0.01	4.29	326	89	34.38
119	4.29	0.88	0.00	0.00	0.00	0.88	1.04	0.01	4.31	331	90	34.47
120	4.31	0.88	0.00	0.00	0.00	0.88	1.04	0.01	4.32	335	91	34.55
121	4.32	0.88	0.00	0.00	0.00	0.88	1.03	0.01	4.33	339	92	34.63
122	4.33	0.88	0.00	0.00	0.00	0.88	1.03	0.01	4.35	344	93	34.71
123	4.35	0.89	0.00	0.00	0.00	0.89	1.03	0.01	4.36	348	94	34.79
124	4.36	0.89	0.00	0.00	0.00	0.89	1.03	0.01	4.37	352	95	34.86
125	4.37	0.89	0.00	0.00	0.00	0.89	1.02	0.01	4.38	357	96	34.94
126	4.38	0.89	0.00	0.00	0.00	0.89	1.02	0.01	4.39	361	97	35.01
127	4.39	0.89	0.00	0.00	0.00	0.89	1.02	0.01	4.40	365	98	35.08
128	4.40	0.89	0.00	0.00	0.00	0.89	1.02	0.01	4.41	370	99	35.14
129	4.41	0.90	0.00	0.00	0.00	0.90	1.02	0.01	4.42	374	100	35.21
130	4.42	0.90	0.00	0.00	0.00	0.90	1.01	0.01	4.43	379	101	35.27
131	4.43	0.90	0.00	0.00	0.00	0.90	1.01	0.01	4.44	383	102	35.33
132	4.44	0.90	0.00	0.00	0.00	0.90	1.01	0.01	4.45	388	103	35.39
133	4.45	0.90	0.00	0.00	0.00	0.90	1.01	0.01	4.46	392	104	35.45
134	4.46	0.90	0.00	0.00	0.00	0.90	1.01	0.01	4.47	397	105	35.50
135	4.47	0.90	0.00	0.00	0.00	0.90	1.01	0.01	4.48	401	106	35.56
136	4.48	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.48	405	107	35.61
137	4.48	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.49	410	108	35.66
138	4.49	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.50	414	109	35.71
139	4.50	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.51	419	110	35.76
140	4.51	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.52	424	111	35.80
141	4.52	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.52	428	112	35.85
142	4.52	0.91	0.00	0.00	0.00	0.91	1.00	0.01	4.53	433	113	35.89
143	4.53	0.91	0.00	0.00	0.00	0.91	0.99	0.01	4.54	437	114	35.93
144	4.54	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.54	442	115	35.98
145	4.54	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.55	446	116	36.02
146	4.55	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.55	451	117	36.06
147	4.55	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.56	455	118	36.09
148	4.56	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.57	460	119	36.13
149	4.57	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.57	464	120	36.17
150	4.57	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.58	469	121	36.20
151	4.58	0.92	0.00	0.00	0.00	0.92	0.99	0.01	4.58	474	122	36.23
152	4.58	0.92	0.00	0.00	0.00	0.92	0.98	0.01	4.59	478	123	36.27
153	4.59	0.92	0.00	0.00	0.00	0.92	0.98	0.00	4.59	483	124	36.30
154	4.59	0.92	0.00	0.00	0.00	0.92	0.98	0.00	4.60	487	125	36.33
155	4.60	0.93	0.00	0.00	0.00	0.93	0.98	0.00	4.60	492	126	36.36
156	4.60	0.93	0.00	0.00	0.00	0.93	0.98	0.00	4.61	497	127	36.39
157	4.61	0.93	0.00	0.00	0.00	0.93	0.98	0.00	4.61	501	128	36.42
158	4.61	0.93	0.00	0.00	0.00	0.93	0.98	0.00	4.61	506	129	36.44
159	4.61	0.93	0.00	0.00	0.00	0.93	0.98	0.00	4.62	510	130	36.47
160	4.62	0.93	0.00	0.00	0.00	0.93	0.98	0.00	4.62	515	131	36.50

Table K-3

KIGORIAK ICEBREAKER

RIDGE 17
Level ice = 0.51 m

28-Jun-90

INPUT OF SHIP CHARACTERISTICS	
BEAM	18.25 (m)
LENGTH	84.4 (m)
DISTMAXBEAM	25.3 (m)
DISPLACEMENT	6550 (Tons)
ADDED MASS	1.09 (-)
BOLLARD THRUST	1.8 (MN)
MAXIMUM THRUST	1.8 (MN)
STARTSPEED	7.50 (m/sec)
MINSPEED	0.01 (m/sec)

INPUT OF DESIRED ICE VARIABLES	
ICE THICKNESS	0.51 (m)
RIDGE CONSDEPTH	0.39 (m)
RIDGE UNCONSDEPTH	5.30 (m)
RIDGE WIDTH	40.00 (m)
DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL (m)	LEVEL ICE (m)	CONSOLID (m)	UNCONSO (m)
0	0.5	0.5	0.5
20	0.5	0.5	0.5
20	0.5	0.9	5.8
60	0.5	0.9	5.8
60	0.5	0.5	0.5
904	0.5	0.5	0.5

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	2.75 (-)
CONSTANT C1	0.20 (-)
RUBBLE ICE	
CONSTANT Cl	0.25 (-)
CONSTANT alfa	1.20 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

1 SHIP STARTING SPEED (m/s)	2 CALCULATED LEVEL ICE RESISTANCE (MN)	3 RIDGE PENETRAT. FUNCTION (-)	4 CALCULATED RIDGE CONS. RESISTANCE (MN)	5 CALCULATED RIDGE UNCON. RESISTANCE (MN)	6 TOTAL ICE RESISTANCE (MN)	7 SHIP THRUST (MN)	8 ACCELE-RATION dv/dt (m/s2)	9 SHIP TRAVEL IN SECOND (m)	10 SHIP TRAVELLED DISTANCE (m)	11 TIME SEC	12 RESIST. PER UNIT WIDTH (kN/m)
7.50	1.01	0.00	0.00	0.00	1.01	1.05	0.01	7.51	8	1	55.44
7.51	1.01	0.00	0.00	0.00	1.01	1.05	0.01	7.51	15	2	55.48
7.51	1.01	0.00	0.00	0.00	1.01	1.05	0.01	7.52	23	3	55.51
7.52	1.01	0.10	0.07	0.35	1.44	1.05	-0.05	7.46	30	4	78.71
7.46	1.01	0.28	0.21	1.04	2.25	1.05	-0.17	7.29	37	5	123.40
7.29	0.99	0.52	0.36	1.93	3.30	1.07	-0.31	6.98	44	6	180.97
6.98	0.95	0.72	0.50	2.64	4.10	1.10	-0.42	6.56	51	7	224.59
6.56	0.90	0.86	0.57	3.19	4.67	1.14	-0.49	6.07	57	8	255.69
6.07	0.84	0.92	0.57	3.40	4.82	1.19	-0.51	5.56	62	9	264.03
5.56	0.78	0.96	0.55	3.54	4.88	1.24	-0.51	5.05	68	10	267.25
5.05	0.72	0.79	0.42	2.93	4.08	1.29	-0.39	4.66	72	11	223.33
4.66	0.68	0.64	0.31	2.35	3.34	1.33	-0.28	4.38	77	12	183.11
4.38	0.65	0.48	0.22	1.77	2.64	1.36	-0.18	4.20	81	13	144.44
4.20	0.62	0.35	0.16	1.28	2.06	1.38	-0.09	4.11	85	14	112.72
4.11	0.61	0.29	0.13	1.05	1.79	1.39	-0.06	4.05	89	15	98.32
4.05	0.61	0.18	0.08	0.67	1.35	1.39	0.01	4.06	93	16	74.06
4.06	0.61	0.11	0.05	0.39	1.04	1.39	0.05	4.11	97	17	57.09
4.11	0.61	0.08	0.04	0.30	0.94	1.39	0.06	4.17	101	18	51.78
4.17	0.62	0.04	0.02	0.16	0.80	1.38	0.08	4.25	105	19	43.65
4.25	0.63	0.03	0.01	0.11	0.75	1.37	0.09	4.34	110	20	41.35
4.34	0.64	0.01	0.00	0.04	0.68	1.37	0.10	4.43	114	21	37.36
4.43	0.65	0.00	0.00	0.00	0.65	1.36	0.10	4.53	119	22	35.70
4.53	0.66	0.00	0.00	0.00	0.66	1.35	0.10	4.63	123	23	36.33
4.63	0.67	0.00	0.00	0.00	0.67	1.34	0.09	4.72	128	24	36.95
4.72	0.69	0.00	0.00	0.00	0.69	1.33	0.09	4.81	133	25	37.55
4.81	0.70	0.00	0.00	0.00	0.70	1.32	0.09	4.90	138	26	38.13
4.90	0.71	0.00	0.00	0.00	0.71	1.31	0.08	4.98	143	27	38.69
4.98	0.72	0.00	0.00	0.00	0.72	1.30	0.08	5.06	148	28	39.23
5.06	0.73	0.00	0.00	0.00	0.73	1.29	0.08	5.14	153	29	39.76
5.14	0.73	0.00	0.00	0.00	0.73	1.29	0.08	5.22	158	30	40.27
5.22	0.74	0.00	0.00	0.00	0.74	1.28	0.07	5.30	164	31	40.77
5.30	0.75	0.00	0.00	0.00	0.75	1.27	0.07	5.37	169	32	41.25
5.37	0.76	0.00	0.00	0.00	0.76	1.26	0.07	5.44	174	33	41.72
5.44	0.77	0.00	0.00	0.00	0.77	1.26	0.07	5.51	180	34	42.17
5.51	0.78	0.00	0.00	0.00	0.78	1.25	0.07	5.57	185	35	42.61
5.57	0.79	0.00	0.00	0.00	0.79	1.24	0.06	5.64	191	36	43.03
5.64	0.79	0.00	0.00	0.00	0.79	1.24	0.06	5.70	197	37	43.45
5.70	0.80	0.00	0.00	0.00	0.80	1.23	0.06	5.76	203	38	43.85
5.76	0.81	0.00	0.00	0.00	0.81	1.22	0.06	5.82	208	39	44.23
5.82	0.81	0.00	0.00	0.00	0.81	1.22	0.06	5.87	214	40	44.61
5.87	0.82	0.00	0.00	0.00	0.82	1.21	0.05	5.93	220	41	44.97
5.93	0.83	0.00	0.00	0.00	0.83	1.21	0.05	5.98	226	42	45.33
5.98	0.83	0.00	0.00	0.00	0.83	1.20	0.05	6.03	232	43	45.67
6.03	0.84	0.00	0.00	0.00	0.84	1.20	0.05	6.08	238	44	46.00
6.08	0.85	0.00	0.00	0.00	0.85	1.19	0.05	6.13	244	45	46.32
6.13	0.85	0.00	0.00	0.00	0.85	1.19	0.05	6.18	251	46	46.64
6.18	0.86	0.00	0.00	0.00	0.86	1.18	0.05	6.22	257	47	46.94
6.22	0.86	0.00	0.00	0.00	0.86	1.18	0.04	6.27	263	48	47.23
6.27	0.87	0.00	0.00	0.00	0.87	1.17	0.04	6.31	269	49	47.52
6.31	0.87	0.00	0.00	0.00	0.87	1.17	0.04	6.35	276	50	47.79
6.35	0.88	0.00	0.00	0.00	0.88	1.16	0.04	6.39	282	51	48.06

Table K-4

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

KIGORIAK ICEBREAKER

RIDGE 18
Level ice = 0.46 m

28-Jun-90

Row	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	18.25 (m)
9	LENGTH	84.4 (m)
10	DISTMAXBEAM	25.3 (m)
11	DISPLACEMENT	6550 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.8 (MN)
14	MAXIMUM THRUST	1.8 (MN)
15	STARTSPEED	8.00 (m/sec)
16	MINSPEED	0.01 (m/sec)
17		

Row	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	0.46 (m)
20	RIDGE CONSDEPTH	1.10 (m)
21	RIDGE UNCONSDEPTH	3.70 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL (m)	LEVEL ICE (m)	CONSOLID (m)	UNCONSO (m)
0	0.5	0.5	0.5
20	0.5	0.5	0.5
20	0.5	1.6	4.2
60	0.5	1.6	4.2
60	0.5	0.5	0.5
904	0.5	0.5	0.5

INPUT FROM MODEL TEST RESULTS

LEVEL ICE	
CONSTANT C0	2.75 (-)
CONSTANT C1	0.20 (-)
RUBBLE ICE	
CONSTANT Cl	0.25 (-)
CONSTANT alfa	1.20 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.76
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26–28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	8.00	0.95	0.00	0.00	0.00	0.95	1.00	0.01	8.01	8	1	52.28
31	8.01	0.95	0.00	0.00	0.00	0.95	1.00	0.01	8.01	16	2	52.31
32	8.01	0.96	0.00	0.00	0.00	0.96	1.00	0.01	8.02	24	3	52.35
33	8.02	0.96	0.10	0.25	0.23	1.44	1.00	-0.06	7.96	32	4	78.64
34	7.96	0.95	0.37	0.96	0.88	2.78	1.00	-0.25	7.71	40	5	152.58
35	7.71	0.92	0.59	1.52	1.42	3.86	1.03	-0.40	7.31	47	6	211.75
36	7.31	0.88	0.76	1.91	1.87	4.66	1.07	-0.50	6.81	54	7	255.48
37	6.81	0.83	0.90	2.09	2.15	5.07	1.12	-0.55	6.25	60	8	277.62
38	6.25	0.77	0.94	2.07	2.27	5.10	1.17	-0.55	5.70	66	9	279.50
39	5.70	0.71	0.79	1.63	1.90	4.24	1.23	-0.42	5.28	71	10	232.48
40	5.28	0.67	0.64	1.24	1.53	3.43	1.27	-0.30	4.98	76	11	187.84
41	4.98	0.63	0.46	0.89	1.15	2.67	1.30	-0.19	4.79	81	12	148.55
42	4.79	0.61	0.35	0.63	0.83	2.07	1.32	-0.11	4.68	86	13	113.49
43	4.68	0.60	0.22	0.40	0.53	1.54	1.33	-0.03	4.65	90	14	84.20
44	4.65	0.60	0.16	0.32	0.43	1.35	1.33	0.00	4.65	95	15	74.18
45	4.65	0.60	0.11	0.19	0.25	1.04	1.33	0.04	4.69	100	16	56.94
46	4.69	0.60	0.06	0.10	0.14	0.85	1.33	0.07	4.76	104	17	46.31
47	4.76	0.61	0.03	0.05	0.07	0.74	1.32	0.08	4.84	109	18	40.40
48	4.84	0.62	0.01	0.02	0.02	0.66	1.32	0.09	4.94	114	19	36.27
49	4.94	0.63	0.00	0.00	0.00	0.63	1.31	0.09	5.03	119	20	34.48
50	5.03	0.64	0.00	0.00	0.00	0.64	1.30	0.09	5.12	124	21	35.03
51	5.12	0.65	0.00	0.00	0.00	0.65	1.29	0.09	5.21	129	22	35.57
52	5.21	0.66	0.00	0.00	0.00	0.66	1.28	0.09	5.30	135	23	36.09
53	5.30	0.67	0.00	0.00	0.00	0.67	1.27	0.08	5.38	140	24	36.59
54	5.38	0.68	0.00	0.00	0.00	0.68	1.26	0.08	5.46	146	25	37.08
55	5.46	0.69	0.00	0.00	0.00	0.69	1.25	0.08	5.54	151	26	37.56
56	5.54	0.69	0.00	0.00	0.00	0.69	1.25	0.08	5.62	157	27	38.02
57	5.62	0.70	0.00	0.00	0.00	0.70	1.24	0.08	5.70	162	28	38.47
58	5.70	0.71	0.00	0.00	0.00	0.71	1.23	0.07	5.77	168	29	38.90
59	5.77	0.72	0.00	0.00	0.00	0.72	1.22	0.07	5.84	174	30	39.33
60	5.84	0.73	0.00	0.00	0.00	0.73	1.22	0.07	5.91	180	31	39.74
61	5.91	0.73	0.00	0.00	0.00	0.73	1.21	0.07	5.98	186	32	40.14
62	5.98	0.74	0.00	0.00	0.00	0.74	1.20	0.06	6.04	192	33	40.52
63	6.04	0.75	0.00	0.00	0.00	0.75	1.20	0.06	6.10	198	34	40.90
64	6.10	0.75	0.00	0.00	0.00	0.75	1.19	0.06	6.16	204	35	41.27
65	6.16	0.76	0.00	0.00	0.00	0.76	1.18	0.06	6.22	210	36	41.62
66	6.22	0.77	0.00	0.00	0.00	0.77	1.18	0.06	6.28	217	37	41.96
67	6.28	0.77	0.00	0.00	0.00	0.77	1.17	0.06	6.34	223	38	42.30
68	6.34	0.78	0.00	0.00	0.00	0.78	1.17	0.05	6.39	229	39	42.63
69	6.39	0.78	0.00	0.00	0.00	0.78	1.16	0.05	6.45	236	40	42.94
70	6.45	0.79	0.00	0.00	0.00	0.79	1.16	0.05	6.50	242	41	43.25
71	6.50	0.79	0.00	0.00	0.00	0.79	1.15	0.05	6.55	249	42	43.55
72	6.55	0.80	0.00	0.00	0.00	0.80	1.15	0.05	6.59	256	43	43.83
73	6.59	0.81	0.00	0.00	0.00	0.81	1.14	0.05	6.64	262	44	44.12
74	6.64	0.81	0.00	0.00	0.00	0.81	1.14	0.05	6.69	269	45	44.39
75	6.69	0.81	0.00	0.00	0.00	0.81	1.13	0.04	6.73	276	46	44.65
76	6.73	0.82	0.00	0.00	0.00	0.82	1.13	0.04	6.77	282	47	44.91
77	6.77	0.82	0.00	0.00	0.00	0.82	1.12	0.04	6.82	289	48	45.16
78	6.82	0.83	0.00	0.00	0.00	0.83	1.12	0.04	6.86	296	49	45.40
79	6.86	0.83	0.00	0.00	0.00	0.83	1.11	0.04	6.90	303	50	45.64
80	6.90	0.84	0.00	0.00	0.00	0.84	1.11	0.04	6.93	310	51	45.87

Table K-5

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

POLAR STAR ICEBREAKER

LIMITING RIDGE
Level ice = 0.5 m

28-Jun-90

7	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	25.45 (m)
9	LENGTH	107.3 (m)
10	DISTMAXBEAM	47.3 (m)
11	DISPLACEMENT	11020 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.85 (MN)
14	MAXIMUM THRUST	1.85 (MN)
15	STARTSPEED	4.50 (m/sec)
16	MINSPEED	0.01 (m/sec)
17		
18	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	0.50 (m)
20	RIDGE CONSDEPTH	1.25 (m)
21	RIDGE UNCONSDEPTH	3.75 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL (m)	LEVEL ICE (m)	CONSOLID (m)	UNCONSO (m)
0	0.5	0.5	0.5
20	0.5	0.5	0.5
20	0.5	1.8	4.3
60	0.5	1.8	4.3
60	0.5	0.5	0.5
1133	0.5	0.5	0.5

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	3.6 (-)
CONSTANT C1	0.2 (-)
RUBBLE ICE	
CONSTANT Cl	0.20 (-)
CONSTANT alfa	1.24 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSI	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTO	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26–28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	4.50	1.01	0.00	0.00	0.00	1.01	1.00	0.00	4.50	4	1	39.58
31	4.50	1.01	0.00	0.00	0.00	1.01	1.00	0.00	4.50	9	2	39.58
32	4.50	1.01	0.00	0.00	0.00	1.01	1.00	0.00	4.50	13	3	39.57
33	4.50	1.01	0.00	0.00	0.00	1.01	1.00	0.00	4.50	18	4	39.57
34	4.50	1.01	0.00	0.00	0.00	1.01	1.00	0.00	4.50	22	5	39.57
35	4.50	1.01	0.00	0.00	0.00	1.01	1.00	0.00	4.50	27	6	39.56
36	4.50	1.01	0.10	0.32	0.20	1.52	1.00	-0.04	4.45	31	7	59.85
37	4.45	1.00	0.19	0.63	0.39	2.02	1.01	-0.08	4.37	36	8	79.18
38	4.37	0.98	0.28	0.93	0.58	2.49	1.02	-0.12	4.25	40	9	97.90
39	4.25	0.96	0.37	1.19	0.75	2.91	1.05	-0.15	4.09	44	10	114.28
40	4.09	0.94	0.46	1.46	0.94	3.33	1.08	-0.19	3.90	48	11	130.88
41	3.90	0.90	0.46	1.42	0.94	3.28	1.11	-0.18	3.73	52	12	128.15
42	3.73	0.87	0.52	1.59	1.08	3.54	1.15	-0.20	3.53	55	13	139.09
43	3.53	0.84	0.59	1.75	1.22	3.81	1.18	-0.22	3.31	59	14	149.76
44	3.31	0.80	0.66	1.87	1.35	4.03	1.22	-0.23	3.07	62	15	158.16
45	3.07	0.76	0.66	1.81	1.35	3.92	1.27	-0.22	2.85	65	16	153.98
46	2.85	0.72	0.72	1.91	1.47	4.10	1.31	-0.23	2.62	67	17	161.17
47	2.62	0.68	0.62	1.59	1.28	3.55	1.35	-0.18	2.44	70	18	139.50
48	2.44	0.65	0.59	1.47	1.22	3.33	1.39	-0.16	2.28	72	19	130.98
49	2.28	0.62	0.59	1.43	1.22	3.26	1.42	-0.15	2.12	74	20	128.26
50	2.12	0.60	0.63	1.40	1.30	3.39	1.45	-0.16	1.96	76	21	133.04
51	1.96	0.57	0.54	1.23	1.11	2.91	1.48	-0.12	1.84	78	22	114.43
52	1.84	0.55	0.58	1.30	1.20	3.05	1.50	-0.13	1.71	80	23	119.69
53	1.71	0.53	0.50	1.06	1.02	2.63	1.53	-0.09	1.62	81	24	103.41
54	1.62	0.51	0.50	1.06	1.02	2.60	1.54	-0.09	1.53	83	25	102.00
55	1.53	0.49	0.53	1.11	1.09	2.70	1.56	-0.09	1.44	84	26	105.97
56	1.44	0.48	0.44	0.90	0.91	2.29	1.58	-0.06	1.38	85	27	89.93
57	1.38	0.47	0.44	0.89	0.91	2.27	1.59	-0.06	1.32	87	28	89.08
58	1.32	0.46	0.47	0.93	0.98	2.35	1.60	-0.06	1.26	88	29	92.27
59	1.26	0.45	0.47	0.92	0.96	2.32	1.61	-0.06	1.20	89	30	91.35
60	1.20	0.44	0.40	0.78	0.82	2.03	1.62	-0.03	1.17	90	31	79.84
61	1.17	0.43	0.40	0.77	0.82	2.02	1.63	-0.03	1.14	92	32	79.38
62	1.14	0.43	0.42	0.81	0.87	2.10	1.64	-0.04	1.10	93	33	82.46
63	1.10	0.42	0.42	0.80	0.87	2.08	1.64	-0.04	1.06	94	34	81.92
64	1.06	0.41	0.35	0.66	0.72	1.80	1.65	-0.01	1.05	95	35	70.54
65	1.05	0.41	0.35	0.68	0.72	1.79	1.65	-0.01	1.04	96	36	70.39
66	1.04	0.41	0.37	0.69	0.75	1.85	1.65	-0.02	1.02	97	37	72.56
67	1.02	0.41	0.37	0.68	0.75	1.84	1.66	-0.02	1.01	98	38	72.35
68	1.01	0.40	0.30	0.56	0.82	1.59	1.66	0.01	1.01	99	39	62.51
69	1.01	0.40	0.30	0.57	0.82	1.59	1.66	0.01	1.02	100	40	62.58
70	1.02	0.40	0.30	0.57	0.82	1.59	1.66	0.01	1.02	101	41	62.65
71	1.02	0.41	0.32	0.59	0.85	1.65	1.66	0.00	1.02	102	42	64.64
72	1.02	0.41	0.32	0.56	0.85	1.65	1.66	0.00	1.02	103	43	64.65
73	1.02	0.41	0.26	0.48	0.53	1.41	1.66	0.02	1.04	104	44	55.39
74	1.04	0.41	0.26	0.48	0.53	1.42	1.65	0.02	1.06	105	45	55.62
75	1.06	0.41	0.26	0.48	0.53	1.42	1.65	0.02	1.08	106	46	55.84
76	1.08	0.42	0.27	0.50	0.55	1.47	1.65	0.01	1.10	107	47	57.60
77	1.10	0.42	0.27	0.51	0.55	1.47	1.64	0.01	1.11	108	48	57.77
78	1.11	0.42	0.20	0.39	0.42	1.23	1.64	0.03	1.15	109	49	48.18
79	1.15	0.43	0.20	0.39	0.42	1.24	1.63	0.03	1.18	111	50	48.53
80	1.18	0.43	0.21	0.41	0.44	1.28	1.63	0.03	1.21	112	51	50.44

Table K-6

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

POLAR STAR ICEBREAKER

LIMITING RIDGE
Level ice = 1.00 m

28-Jun-90

	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	25.45 (m)
9	LENGTH	107.3 (m)
10	DISTMAXBEAM	47.3 (m)
11	DISPLACEMENT	11020 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.85 (MN)
14	MAXIMUM THRUST	1.85 (MN)
15	STARTSPEED	1.75 (m/sec)
16	MINSPEED	0.01 (m/sec)
17		

	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	1.00 (m)
20	RIDGE CONSDEPTH	0.50 (m)
21	RIDGE UNCONSDEPTH	1.50 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	5.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL	LEVEL ICE	CONSOLID	UNCONSO
(m)	(m)	(m)	(m)
0	1.0	1.0	1.0
5	1.0	1.0	1.0
5	1.0	1.5	2.5
45	1.0	1.5	2.5
45	1.0	1.0	1.0
1118	1.0	1.0	1.0

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	3.6 (-)
CONSTANT C1	0.2 (-)
RUBBLE ICE	
CONSTANT Cl	0.20 (-)
CONSTANT alfa	1.24 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSI	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26 27 28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	1.75	1.52	0.00	0.00	0.00	1.52	1.52	0.00	1.75	2	1	59.80
31	1.75	1.52	0.00	0.00	0.00	1.52	1.52	0.00	1.75	3	2	59.80
32	1.75	1.52	0.00	0.00	0.00	1.52	1.52	0.00	1.75	5	3	59.80
33	1.75	1.52	0.00	0.00	0.00	1.52	1.52	0.00	1.75	7	4	59.80
34	1.75	1.52	0.00	0.00	0.00	1.52	1.52	0.00	1.75	9	5	59.79
35	1.75	1.52	0.00	0.00	0.00	1.52	1.52	0.00	1.75	10	6	59.79
36	1.75	1.52	0.10	0.05	0.06	1.63	1.52	-0.01	1.74	12	7	64.24
37	1.74	1.52	0.10	0.05	0.06	1.63	1.52	-0.01	1.73	14	8	64.10
38	1.73	1.52	0.10	0.05	0.06	1.63	1.52	-0.01	1.72	16	9	63.97
39	1.72	1.51	0.19	0.10	0.12	1.73	1.52	-0.02	1.70	17	10	68.17
40	1.70	1.51	0.19	0.10	0.12	1.73	1.53	-0.02	1.69	19	11	67.91
41	1.69	1.50	0.19	0.10	0.12	1.72	1.53	-0.02	1.67	21	12	67.66
42	1.67	1.49	0.28	0.15	0.19	1.83	1.53	-0.02	1.65	22	13	71.71
43	1.65	1.49	0.28	0.14	0.19	1.82	1.54	-0.02	1.62	24	14	71.34
44	1.62	1.48	0.37	0.19	0.24	1.91	1.54	-0.03	1.59	26	15	74.89
45	1.59	1.47	0.37	0.18	0.24	1.89	1.55	-0.03	1.57	27	16	74.41
46	1.57	1.46	0.37	0.18	0.24	1.88	1.55	-0.03	1.54	29	17	73.94
47	1.54	1.45	0.46	0.23	0.30	1.97	1.56	-0.03	1.50	30	18	77.60
48	1.50	1.44	0.46	0.22	0.30	1.96	1.57	-0.03	1.47	32	19	77.02
49	1.47	1.43	0.46	0.22	0.30	1.95	1.57	-0.03	1.44	33	20	76.47
50	1.44	1.41	0.46	0.22	0.30	1.93	1.58	-0.03	1.41	35	21	75.95
51	1.41	1.40	0.52	0.25	0.35	2.00	1.58	-0.03	1.38	36	22	78.47
52	1.38	1.39	0.52	0.24	0.35	1.98	1.59	-0.03	1.34	37	23	77.88
53	1.34	1.38	0.52	0.24	0.35	1.97	1.60	-0.03	1.31	39	24	77.32
54	1.31	1.37	0.59	0.27	0.39	2.03	1.60	-0.04	1.28	40	25	79.86
55	1.28	1.36	0.59	0.27	0.39	2.02	1.61	-0.03	1.24	41	26	79.23
56	1.24	1.35	0.59	0.26	0.39	2.00	1.62	-0.03	1.21	42	27	78.63
57	1.21	1.34	0.59	0.26	0.39	1.99	1.62	-0.03	1.18	43	28	78.07
58	1.18	1.32	0.66	0.28	0.43	2.04	1.63	-0.03	1.14	45	29	80.22
59	1.14	1.31	0.66	0.28	0.43	2.03	1.63	-0.03	1.11	46	30	79.60
60	1.11	1.30	0.66	0.28	0.43	2.01	1.64	-0.03	1.08	47	31	79.01
61	1.08	1.29	0.66	0.27	0.43	2.00	1.65	-0.03	1.05	48	32	78.45
62	1.05	1.28	0.72	0.29	0.47	2.05	1.65	-0.03	1.02	49	33	80.45
63	1.02	1.27	0.72	0.29	0.47	2.03	1.66	-0.03	0.99	50	34	79.84
64	0.99	1.26	0.62	0.25	0.41	1.92	1.66	-0.02	0.97	51	35	75.31
65	0.97	1.25	0.62	0.25	0.41	1.91	1.67	-0.02	0.95	52	36	74.93
66	0.95	1.24	0.62	0.24	0.41	1.90	1.67	-0.02	0.93	53	37	74.57
67	0.93	1.24	0.68	0.27	0.45	1.96	1.67	-0.02	0.90	54	38	76.82
68	0.90	1.23	0.68	0.26	0.45	1.94	1.68	-0.02	0.88	55	39	76.39
69	0.88	1.22	0.59	0.23	0.39	1.84	1.68	-0.01	0.87	55	40	72.20
70	0.87	1.22	0.59	0.22	0.39	1.83	1.69	-0.01	0.86	56	41	71.97
71	0.86	1.21	0.59	0.22	0.39	1.83	1.69	-0.01	0.85	57	42	71.76
72	0.85	1.21	0.63	0.24	0.42	1.87	1.69	-0.01	0.83	58	43	73.29
73	0.83	1.20	0.63	0.24	0.42	1.86	1.69	-0.01	0.82	59	44	73.03
74	0.82	1.20	0.63	0.23	0.42	1.85	1.70	-0.01	0.80	60	45	72.78
75	0.80	1.20	0.54	0.20	0.36	1.75	1.70	0.00	0.80	60	46	68.81
76	0.80	1.19	0.54	0.20	0.36	1.75	1.70	0.00	0.80	61	47	68.73
77	0.80	1.19	0.54	0.20	0.36	1.75	1.70	0.00	0.79	62	48	68.66
78	0.79	1.19	0.58	0.21	0.39	1.79	1.70	-0.01	0.78	63	49	70.30
79	0.78	1.19	0.58	0.21	0.39	1.79	1.70	-0.01	0.78	63	50	70.17
80	0.78	1.19	0.58	0.21	0.39	1.78	1.70	-0.01	0.77	64	51	70.05

Table K-7

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

POLAR STAR ICEBREAKER

LIMITING RIDGE
Level ice = 1.25 m

28-Jun-90

	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	25.45 (m)
9	LENGTH	107.3 (m)
10	DISTMAXBEAM	47.3 (m)
11	DISPLACEMENT	11020 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.85 (MN)
14	MAXIMUM THRUST	1.85 (MN)
15	STARTSPEED	0.68 (m/sec)
16	MINSPEED	0.01 (m/sec)
17		

	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	1.25 (m)
20	RIDGE CONSDEPTH	0.25 (m)
21	RIDGE UNCONSDEPTH	0.75 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	1.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL	LEVEL ICE	CONSOLID	UNCONSO
(m)	(m)	(m)	(m)
0	1.3	1.3	1.3
1	1.3	1.3	1.3
1	1.3	1.5	2.0
41	1.3	1.5	2.0
41	1.3	1.3	1.3
1114	1.3	1.3	1.3

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	3.6 (-)
CONSTANT C1	0.2 (-)
RUBBLE ICE	
CONSTANT Cl	0.20 (-)
CONSTANT alfa	1.24 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26 27 28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	1	1	67.84
31	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	1	2	67.83
32	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	2	3	67.82
33	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	3	4	67.82
34	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	3	5	67.81
35	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	4	6	67.80
36	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	5	7	67.80
37	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	5	8	67.79
38	0.68	1.73	0.00	0.00	0.00	1.73	1.72	0.00	0.68	6	9	67.79
39	0.68	1.73	0.10	0.01	0.03	1.76	1.72	0.00	0.67	7	10	69.26
40	0.67	1.72	0.10	0.01	0.03	1.76	1.72	0.00	0.67	7	11	69.20
41	0.67	1.72	0.10	0.01	0.03	1.76	1.72	0.00	0.67	8	12	69.15
42	0.67	1.72	0.10	0.01	0.03	1.76	1.72	0.00	0.66	9	13	69.10
43	0.66	1.72	0.10	0.01	0.03	1.76	1.72	0.00	0.66	9	14	69.05
44	0.66	1.72	0.10	0.01	0.03	1.76	1.72	0.00	0.66	10	15	69.00
45	0.66	1.72	0.10	0.01	0.03	1.75	1.73	0.00	0.66	11	16	68.95
46	0.66	1.72	0.19	0.02	0.05	1.79	1.73	-0.01	0.65	11	17	70.34
47	0.65	1.71	0.19	0.02	0.05	1.79	1.73	-0.01	0.65	12	18	70.25
48	0.65	1.71	0.19	0.02	0.05	1.79	1.73	0.00	0.64	13	19	70.16
49	0.64	1.71	0.19	0.02	0.05	1.78	1.73	0.00	0.64	13	20	70.08
50	0.64	1.71	0.19	0.02	0.05	1.78	1.73	0.00	0.63	14	21	70.00
51	0.63	1.71	0.19	0.02	0.05	1.78	1.73	0.00	0.63	15	22	69.92
52	0.63	1.70	0.19	0.02	0.05	1.78	1.73	0.00	0.62	15	23	69.85
53	0.62	1.70	0.28	0.03	0.08	1.81	1.73	-0.01	0.62	16	24	71.20
54	0.62	1.70	0.28	0.03	0.08	1.81	1.73	-0.01	0.61	16	25	71.08
55	0.61	1.70	0.28	0.03	0.08	1.81	1.73	-0.01	0.61	17	26	70.97
56	0.61	1.69	0.28	0.03	0.08	1.80	1.74	-0.01	0.60	18	27	70.86
57	0.60	1.69	0.28	0.03	0.08	1.80	1.74	-0.01	0.59	18	28	70.76
58	0.59	1.69	0.28	0.03	0.08	1.80	1.74	-0.01	0.59	19	29	70.66
59	0.59	1.69	0.28	0.03	0.08	1.80	1.74	0.00	0.58	19	30	70.57
60	0.58	1.69	0.28	0.03	0.08	1.79	1.74	0.00	0.58	20	31	70.49
61	0.58	1.68	0.37	0.04	0.10	1.82	1.74	-0.01	0.57	21	32	71.70
62	0.57	1.68	0.37	0.04	0.10	1.82	1.74	-0.01	0.57	21	33	71.57
63	0.57	1.66	0.37	0.04	0.10	1.82	1.74	-0.01	0.56	22	34	71.45
64	0.56	1.67	0.37	0.04	0.10	1.82	1.74	-0.01	0.55	22	35	71.34
65	0.55	1.67	0.37	0.04	0.10	1.81	1.75	-0.01	0.55	23	36	71.23
66	0.55	1.67	0.37	0.04	0.10	1.81	1.75	-0.01	0.54	23	37	71.13
67	0.54	1.67	0.37	0.04	0.10	1.81	1.75	-0.01	0.54	24	38	71.03
68	0.54	1.67	0.37	0.04	0.10	1.81	1.75	0.00	0.53	24	39	70.94
69	0.53	1.66	0.37	0.04	0.10	1.80	1.75	0.00	0.53	25	40	70.85
70	0.53	1.66	0.46	0.05	0.13	1.84	1.75	-0.01	0.52	25	41	72.12
71	0.52	1.66	0.46	0.05	0.13	1.83	1.75	-0.01	0.52	26	42	71.99
72	0.52	1.66	0.46	0.05	0.13	1.83	1.75	-0.01	0.51	26	43	71.87
73	0.51	1.65	0.46	0.05	0.13	1.83	1.75	-0.01	0.50	27	44	71.75
74	0.50	1.65	0.46	0.05	0.13	1.82	1.75	-0.01	0.50	27	45	71.64
75	0.50	1.65	0.46	0.05	0.13	1.82	1.76	-0.01	0.49	28	46	71.53
76	0.49	1.65	0.46	0.05	0.13	1.82	1.76	-0.01	0.49	28	47	71.43
77	0.49	1.64	0.46	0.05	0.13	1.82	1.76	0.00	0.48	29	48	71.34
78	0.48	1.64	0.46	0.05	0.13	1.81	1.76	0.00	0.48	29	49	71.25
79	0.48	1.64	0.52	0.05	0.15	1.84	1.76	-0.01	0.47	30	50	72.17
80	0.47	1.64	0.52	0.05	0.15	1.83	1.76	-0.01	0.47	30	51	72.05

Table K-8

KIGORIAK ICEBREAKER

LIMITING RIDGE
Level ice = 0.50 m

28-Jun-90

INPUT OF SHIP CHARACTERISTICS	
BEAM	18.25 (m)
LENGTH	84.4 (m)
DISTMAXBEAM	25.3 (m)
DISPLACEMENT	6550 (Tons)
ADDED MASS	1.09 (-)
BOLLARD THRUST	1.8 (MN)
MAXIMUM THRUST	1.8 (MN)
STARTSPEED	7.77 (m/sec)
MINSPEED	0.01 (m/sec)

INPUT OF DESIRED ICE VARIABLES	
ICE THICKNESS	0.50 (m)
RIDGE CONSDEPTH	1.65 (m)
RIDGE UNCONSDEPTH	4.95 (m)
RIDGE WIDTH	40.00 (m)
DISTANCE TO RIDGE	20.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL	LEVEL ICE	CONSOLID	UNCONSO
(m)	(m)	(m)	(m)
0	0.5	0.5	0.5
20	0.5	0.5	0.5
20	0.5	2.2	5.5
60	0.5	2.2	5.5
60	0.5	0.5	0.5
904	0.5	0.5	0.5

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	2.75 (-)
CONSTANT C1	0.20 (-)
RUBBLE ICE	
CONSTANT Cl	0.25 (-)
CONSTANT alfa	1.20 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

1	2	3	4	5	6	7	8	9	10	11	12
SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
7.77	1.02	0.00	0.00	0.00	1.02	1.02	0.00	7.77	8	1	55.92
7.77	1.02	0.00	0.00	0.00	1.02	1.02	0.00	7.77	16	2	55.92
7.77	1.02	0.00	0.00	0.00	1.02	1.02	0.00	7.77	23	3	55.93
7.77	1.02	0.10	0.41	0.32	1.75	1.02	-0.10	7.67	31	4	96.16
7.67	1.01	0.37	1.56	1.24	3.82	1.03	-0.39	7.28	38	5	209.08
7.28	0.96	0.59	2.45	2.02	5.43	1.07	-0.61	6.67	45	6	297.68
6.67	0.89	0.72	2.79	2.44	6.12	1.13	-0.70	5.97	51	7	335.35
5.97	0.81	0.86	3.14	2.94	6.89	1.20	-0.80	5.17	56	8	377.47
5.17	0.72	0.92	3.07	3.14	6.92	1.28	-0.79	4.38	60	9	379.38
4.38	0.63	0.94	2.86	3.21	6.70	1.36	-0.75	3.64	64	10	367.19
3.64	0.54	0.88	2.41	2.98	5.93	1.44	-0.63	3.01	67	11	325.02
3.01	0.47	0.79	1.99	2.70	5.16	1.50	-0.51	2.49	70	12	282.82
2.49	0.41	0.71	1.64	2.42	4.48	1.55	-0.41	2.08	72	13	245.25
2.08	0.37	0.64	1.37	2.16	3.90	1.59	-0.32	1.76	73	14	213.72
1.76	0.33	0.55	1.11	1.86	3.30	1.62	-0.23	1.53	75	15	180.56
1.53	0.30	0.55	1.06	1.86	3.22	1.65	-0.22	1.31	76	16	176.42
1.31	0.28	0.48	0.89	1.63	2.79	1.67	-0.16	1.15	77	17	153.04
1.15	0.26	0.48	0.86	1.63	2.75	1.69	-0.15	1.00	78	18	150.48
1.00	0.24	0.41	0.71	1.39	2.34	1.70	-0.09	0.91	79	19	128.29
0.91	0.23	0.41	0.70	1.39	2.32	1.71	-0.09	0.82	80	20	126.96
0.82	0.22	0.41	0.68	1.39	2.29	1.72	-0.08	0.74	81	21	125.70
0.74	0.21	0.35	0.57	1.18	1.96	1.73	-0.03	0.71	82	22	107.19
0.71	0.21	0.35	0.56	1.18	1.95	1.73	-0.03	0.68	82	23	106.75
0.68	0.20	0.35	0.56	1.18	1.94	1.73	-0.03	0.65	83	24	106.33
0.65	0.20	0.29	0.46	0.97	1.63	1.73	0.01	0.67	84	25	89.43
0.67	0.20	0.29	0.46	0.97	1.64	1.73	0.01	0.68	84	26	89.60
0.68	0.20	0.29	0.46	0.97	1.64	1.73	0.01	0.69	85	27	89.77
0.69	0.21	0.29	0.46	0.97	1.64	1.73	0.01	0.71	86	28	89.93
0.71	0.21	0.22	0.36	0.76	1.33	1.73	0.06	0.76	86	29	72.82
0.76	0.21	0.22	0.37	0.76	1.34	1.72	0.05	0.81	87	30	73.43
0.81	0.22	0.22	0.37	0.76	1.35	1.72	0.05	0.87	88	31	74.02
0.87	0.23	0.18	0.31	0.61	1.14	1.71	0.08	0.95	89	32	62.69
0.95	0.23	0.18	0.31	0.61	1.16	1.71	0.08	1.02	90	33	63.50
1.02	0.24	0.18	0.32	0.61	1.17	1.70	0.07	1.10	91	34	64.27
1.10	0.25	0.14	0.25	0.47	0.97	1.69	0.10	1.20	92	35	52.92
1.20	0.26	0.14	0.25	0.47	0.98	1.68	0.10	1.30	94	36	53.85
1.30	0.27	0.11	0.20	0.36	0.83	1.67	0.12	1.41	95	37	45.36
1.41	0.29	0.11	0.20	0.36	0.85	1.66	0.11	1.53	97	38	46.37
1.53	0.30	0.08	0.16	0.27	0.73	1.65	0.13	1.66	98	39	40.00
1.66	0.32	0.06	0.11	0.20	0.63	1.63	0.14	1.80	100	40	34.36
1.80	0.33	0.06	0.12	0.20	0.65	1.62	0.14	1.93	102	41	35.42
1.93	0.35	0.04	0.09	0.14	0.58	1.61	0.14	2.08	104	42	31.81
2.08	0.36	0.03	0.06	0.10	0.53	1.59	0.15	2.23	106	43	29.13
2.23	0.38	0.02	0.04	0.07	0.49	1.58	0.15	2.38	109	44	27.08
2.38	0.40	0.01	0.02	0.03	0.46	1.56	0.15	2.53	111	45	24.99
2.53	0.42	0.00	0.00	0.00	0.42	1.55	0.16	2.69	114	46	22.86
2.69	0.44	0.00	0.00	0.00	0.44	1.53	0.15	2.84	117	47	23.88
2.84	0.45	0.00	0.00	0.00	0.45	1.52	0.15	2.99	120	48	24.83
2.99	0.47	0.00	0.00	0.00	0.47	1.50	0.14	3.14	123	49	25.77
3.14	0.49	0.00	0.00	0.00	0.49	1.49	0.14	3.28	126	50	26.68
3.28	0.50	0.00	0.00	0.00	0.50	1.47	0.14	3.41	130	51	27.58

Table K-9

25	A 1	B 2	C 3	D 4	E 5	F 6	G 7	H 8	I 9	J 10	K 11	L 12

KIGORIAK ICEBREAKER

LIMITING RIDGE
Level ice = 1.00 m

28-Jun-90

	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	18.25 (m)
9	LENGTH	84.4 (m)
10	DISTMAXBEAM	25.3 (m)
11	DISPLACEMENT	6550 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.8 (MN)
14	MAXIMUM THRUST	1.8 (MN)
15	STARTSPEED	3.92 (m/sec)
16	MINSPEED	0.01 (m/sec)

	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	1.00 (m)
20	RIDGE CONSDEPTH	0.80 (m)
21	RIDGE UNCONSDEPTH	2.40 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	5.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL (m)	LEVEL ICE (m)	CONSOLID (m)	UNCONSO (m)
0	1.0	1.0	1.0
5	1.0	1.0	1.0
5	1.0	1.8	3.4
45	1.0	1.8	3.4
45	1.0	1.0	1.0
889	1.0	1.0	1.0

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	2.75 (-)
CONSTANT C1	0.20 (-)
RUBBLE ICE	
CONSTANT Cl	0.25 (-)
CONSTANT alfa	1.20 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26-28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	3.92	1.41	0.00	0.00	0.00	1.41	1.41	0.00	3.92	4	1	77.00
31	3.92	1.41	0.00	0.00	0.00	1.41	1.41	0.00	3.92	8	2	77.01
32	3.92	1.41	0.10	0.10	0.14	1.64	1.41	-0.03	3.89	12	3	89.89
33	3.89	1.40	0.19	0.19	0.27	1.86	1.41	-0.06	3.83	16	4	101.95
34	3.8[illegible]	1.38	0.37	0.37	0.52	2.28	1.42	-0.12	3.70	19	5	124.92
35	3.70	1.36	0.46	0.46	0.65	2.46	1.43	-0.14	3.56	23	6	134.96
36	3.56	1.32	0.59	0.58	0.85	2.75	1.44	-0.18	3.38	26	7	150.60
37	3.38	1.28	0.66	0.62	0.94	2.83	1.46	-0.19	3.18	29	8	155.33
38	3.18	1.24	0.72	0.65	1.02	2.91	1.48	-0.20	2.99	32	9	159.32
39	2.99	1.19	0.78	0.68	1.11	2.98	1.50	-0.21	2.78	35	10	163.23
40	2.78	1.14	0.82	0.68	1.17	3.00	1.52	-0.21	2.57	38	11	164.27
41	2.57	1.09	0.86	0.69	1.23	3.01	1.54	-0.21	2.37	40	12	165.13
42	2.37	1.05	0.90	0.68	1.28	3.00	1.56	-0.20	2.16	42	13	164.63
43	2.16	1.00	0.92	0.66	1.32	2.98	1.58	-0.20	1.97	44	14	163.20
44	1.97	0.96	0.94	0.64	1.35	2.95	1.60	-0.19	1.78	46	15	161.53
45	1.78	0.91	0.96	0.62	1.37	2.90	1.62	-0.18	1.60	48	16	159.06
46	1.60	0.87	0.86	0.53	1.23	2.64	1.64	-0.14	1.46	49	17	144.41
47	1.46	0.84	0.88	0.52	1.25	2.61	1.65	-0.13	1.33	50	18	142.82
48	1.33	0.81	0.78	0.44	1.12	2.37	1.67	-0.10	1.23	52	19	129.84
49	1.23	0.79	0.79	0.43	1.13	2.35	1.68	-0.09	1.13	53	20	128.91
50	1.13	0.76	0.70	0.37	1.00	2.14	1.69	-0.06	1.07	54	21	117.02
51	1.07	0.75	0.71	0.37	1.02	2.13	1.69	-0.06	1.01	55	22	116.85
52	1.01	0.73	0.71	0.36	1.02	2.11	1.70	-0.06	0.95	56	23	115.63
53	0.95	0.72	0.64	0.32	0.91	1.94	1.70	-0.03	0.92	57	24	108.57
54	0.92	0.71	0.64	0.31	0.91	1.93	1.71	-0.03	0.89	58	25	105.93
55	0.89	0.71	0.64	0.31	0.91	1.92	1.71	-0.03	0.86	58	26	105.33
56	0.86	0.70	0.55	0.26	0.78	1.74	1.71	0.00	0.85	59	27	95.36
57	0.85	0.70	0.55	0.26	0.78	1.74	1.71	0.00	0.85	60	28	95.29
58	0.85	0.70	0.55	0.26	0.78	1.74	1.71	0.00	0.85	61	29	95.23
59	0.85	0.70	0.48	0.23	0.68	1.61	1.72	0.02	0.86	62	30	88.12
60	0.86	0.70	0.48	0.23	0.68	1.61	1.71	0.01	0.88	63	31	88.38
61	0.88	0.70	0.41	0.20	0.58	1.48	1.71	0.03	0.91	64	32	81.29
62	0.91	0.71	0.41	0.20	0.58	1.49	1.71	0.03	0.94	65	33	81.82
63	0.94	0.72	0.41	0.20	0.58	1.50	1.71	0.03	0.97	66	34	82.33
64	0.97	0.73	0.35	0.17	0.49	1.39	1.70	0.04	1.01	67	35	76.20
65	1.01	0.74	0.35	0.16	0.49	1.40	1.70	0.04	1.05	68	36	76.91
66	1.05	0.74	0.35	0.16	0.49	1.42	1.69	0.04	1.09	69	37	77.57
67	1.09	0.75	0.29	0.15	0.41	1.31	1.69	0.05	1.14	70	38	71.78
68	1.14	0.77	0.29	0.15	0.41	1.33	1.69	0.05	1.20	71	39	72.61
69	1.20	0.78	0.22	0.12	0.32	1.22	1.68	0.07	1.26	72	40	66.64
70	1.26	0.79	0.22	0.12	0.32	1.23	1.67	0.06	1.32	74	41	67.61
71	1.32	0.81	0.18	0.10	0.26	1.17	1.67	0.07	1.39	75	42	63.88
72	1.39	0.82	0.18	0.10	0.26	1.18	1.66	0.07	1.46	76	43	64.90
73	1.46	0.84	0.14	0.08	0.20	1.12	1.65	0.08	1.53	78	44	61.15
74	1.53	0.86	0.11	0.06	0.15	1.07	1.65	0.08	1.62	80	45	58.59
75	1.62	0.87	0.11	0.07	0.15	1.09	1.64	0.08	1.69	81	46	59.70
76	1.69	0.89	0.08	0.05	0.11	1.06	1.63	0.08	1.77	83	47	57.92
77	1.77	0.91	0.06	0.04	0.08	1.03	1.62	0.08	1.86	85	48	56.44
78	1.86	0.93	0.06	0.04	0.08	1.05	1.61	0.08	1.93	87	49	57.54
79	1.93	0.95	0.04	0.03	0.06	1.04	1.61	0.08	2.01	89	50	56.85
80	2.01	0.97	0.03	0.02	0.04	1.03	1.60	0.08	2.09	91	51	56.43

Table K-10

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12

KIGORIAK ICEBREAKER

LIMITING RIDGE
Level ice = 1.25 m

28-Jun-90

	INPUT OF SHIP CHARACTERISTICS	
8	BEAM	18.25 (m)
9	LENGTH	84.4 (m)
10	DISTMAXBEAM	25.3 (m)
11	DISPLACEMENT	6550 (Tons)
12	ADDED MASS	1.09 (-)
13	BOLLARD THRUST	1.8 (MN)
14	MAXIMUM THRUST	1.8 (MN)
15	STARTSPEED	2.62 (m/sec)
16	MINSPEED	0.01 (m/sec)

	INPUT OF DESIRED ICE VARIABLES	
19	ICE THICKNESS	1.25 (m)
20	RIDGE CONSDEPTH	0.60 (m)
21	RIDGE UNCONSDEPTH	1.80 (m)
22	RIDGE WIDTH	40.00 (m)
23	DISTANCE TO RIDGE	1.00 (m)

RIDGE GEOMETRY COORDINATES

TRAVEL	LEVEL ICE	CONSOLID	UNCONSO
(m)	(m)	(m)	(m)
0	1.3	1.3	1.3
1	1.3	1.3	1.3
1	1.3	1.9	3.1
41	1.3	1.9	3.1
41	1.3	1.3	1.3
885	1.3	1.3	1.3

INPUT FROM MODEL TEST RESULTS	
LEVEL ICE	
CONSTANT C0	2.75 (-)
CONSTANT C1	0.20 (-)
RUBBLE ICE	
CONSTANT Cl	0.25 (-)
CONSTANT alfa	1.20 (-)
ICE DENSITY	
WATER DENSITY	1020 (KG/m3)
ICE DENSITY	900 (KG/m3)
MODEL W DENSIT	1000 (KG/m3)
MODEL I DENSITY	940 (KG/m3)
DENSITY FACTOR	2.00 (-)

RESISTANCE FUNCTION

DISTANCE	RESISTANCE
0.00	0.00
0.10	0.10
0.20	0.19
0.30	0.28
0.40	0.37
0.50	0.46
0.60	0.52
0.70	0.59
0.80	0.66
0.90	0.72
1.00	0.78
1.10	0.82
1.20	0.86
1.30	0.90
1.40	0.92
1.50	0.94
1.60	0.96
1.70	0.97
1.80	0.98
1.90	0.99
2.00	1.00

25	1	2	3	4	5	6	7	8	9	10	11	12
26 27 28	SHIP STARTING SPEED	CALCULATED LEVEL ICE RESISTANCE	RIDGE PENETRAT. FUNCTION	CALCULATED RIDGE CONS. RESISTANCE	CALCULATED RIDGE UNCON. RESISTANCE	TOTAL ICE RESISTANCE	SHIP THRUST	ACCELE-RATION dv/dt	SHIP TRAVEL IN SECOND	SHIP TRAVELLED DISTANCE	TIME	RESIST. PER UNIT WIDTH
29	(m/s)	(MN)	(-)	(MN)	(MN)	(MN)	(MN)	(m/s2)	(m)	(m)	SEC	(kN/m)
30	2.62	1.54	0.00	0.00	0.00	1.54	1.54	0.00	2.62	3	1	84.34
31	2.62	1.54	0.00	0.00	0.00	1.54	1.54	0.00	2.62	5	2	84.33
32	2.62	1.54	0.10	0.05	0.10	1.69	1.54	-0.02	2.60	8	3	92.43
33	2.60	1.53	0.19	0.10	0.19	1.82	1.54	-0.04	2.56	10	4	99.95
34	2.56	1.52	0.28	0.15	0.28	1.95	1.54	-0.06	2.50	13	5	107.11
35	2.50	1.51	0.37	0.19	0.37	2.07	1.55	-0.07	2.43	15	6	113.24
36	2.43	1.48	0.46	0.24	0.46	2.18	1.56	-0.09	2.34	18	7	119.44
37	2.34	1.46	0.52	0.26	0.53	2.25	1.57	-0.10	2.25	20	8	123.37
38	2.25	1.43	0.59	0.29	0.60	2.32	1.58	-0.10	2.14	22	9	127.25
39	2.14	1.40	0.66	0.31	0.66	2.38	1.59	-0.11	2.03	24	10	130.23
40	2.03	1.37	0.72	0.33	0.72	2.42	1.60	-0.12	1.91	26	11	132.77
41	1.91	1.34	0.72	0.32	0.72	2.38	1.61	-0.11	1.81	28	12	130.32
42	1.81	1.31	0.78	0.33	0.79	2.43	1.62	-0.11	1.69	30	13	132.98
43	1.69	1.27	0.82	0.34	0.83	2.44	1.63	-0.11	1.58	31	14	133.85
44	1.58	1.24	0.82	0.33	0.83	2.40	1.64	-0.11	1.47	33	15	131.35
45	1.47	1.21	0.86	0.33	0.87	2.41	1.65	-0.11	1.37	34	16	132.28
46	1.37	1.18	0.90	0.33	0.91	2.42	1.66	-0.11	1.26	35	17	132.36
47	1.26	1.15	0.90	0.32	0.91	2.37	1.67	-0.10	1.16	36	18	129.98
48	1.16	1.12	0.90	0.31	0.91	2.33	1.68	-0.09	1.07	37	19	127.77
49	1.07	1.09	0.92	0.30	0.93	2.33	1.69	-0.09	0.98	38	20	127.56
50	0.98	1.07	0.92	0.29	0.93	2.29	1.70	-0.08	0.90	39	21	125.54
51	0.90	1.04	0.94	0.29	0.95	2.29	1.71	-0.08	0.82	40	22	125.28
52	0.82	1.02	0.94	0.28	0.95	2.25	1.72	-0.07	0.75	41	23	123.43
53	0.75	1.00	0.94	0.27	0.95	2.22	1.73	-0.07	0.68	42	24	121.72
54	0.68	0.98	0.96	0.26	0.97	2.21	1.73	-0.07	0.61	42	25	121.18
55	0.61	0.96	0.96	0.25	0.97	2.18	1.74	-0.06	0.55	43	26	119.64
56	0.55	0.94	0.96	0.25	0.97	2.16	1.75	-0.06	0.49	43	27	118.20
57	0.49	0.93	0.96	0.24	0.97	2.13	1.75	-0.05	0.44	44	28	116.87
58	0.44	0.91	0.86	0.21	0.87	1.99	1.76	-0.03	0.40	44	29	109.12
59	0.40	0.90	0.88	0.21	0.89	1.99	1.76	-0.03	0.37	44	30	109.24
60	0.37	0.89	0.88	0.20	0.89	1.98	1.76	-0.03	0.34	45	31	108.50
61	0.34	0.88	0.88	0.20	0.89	1.97	1.77	-0.03	0.31	45	32	107.82
62	0.31	0.87	0.88	0.20	0.89	1.96	1.77	-0.03	0.29	45	33	107.19
63	0.29	0.87	0.88	0.19	0.89	1.95	1.77	-0.02	0.26	46	34	106.60
64	0.26	0.86	0.88	0.19	0.89	1.94	1.77	-0.02	0.24	46	35	106.05
65	0.24	0.85	0.88	0.19	0.89	1.93	1.78	-0.02	0.22	46	36	105.55
66	0.22	0.85	0.78	0.17	0.79	1.80	1.78	0.00	0.21	46	37	98.88
67	0.21	0.85	0.78	0.16	0.79	1.80	1.78	0.00	0.21	46	38	98.80
68	0.21	0.85	0.78	0.16	0.79	1.80	1.78	0.00	0.21	47	39	98.72
69	0.21	0.84	0.79	0.17	0.80	1.81	1.78	0.00	0.20	47	40	99.32
70	0.20	0.84	0.79	0.17	0.80	1.81	1.78	0.00	0.20	47	41	99.22
71	0.20	0.84	0.79	0.17	0.80	1.81	1.78	0.00	0.19	47	42	99.13
72	0.19	0.84	0.79	0.16	0.80	1.81	1.78	0.00	0.19	47	43	99.04
73	0.19	0.84	0.79	0.16	0.80	1.81	1.78	0.00	0.19	48	44	98.96
74	0.19	0.84	0.79	0.16	0.80	1.80	1.78	0.00	0.18	48	45	98.88
75	0.18	0.84	0.79	0.16	0.80	1.80	1.78	0.00	0.18	48	46	98.81
76	0.18	0.84	0.79	0.16	0.80	1.80	1.78	0.00	0.18	48	47	98.74
77	0.18	0.84	0.79	0.16	0.80	1.80	1.78	0.00	0.18	48	48	98.68
78	0.18	0.84	0.79	0.16	0.80	1.80	1.78	0.00	0.17	49	49	98.62
79	0.17	0.83	0.79	0.16	0.80	1.80	1.78	0.00	0.17	49	50	98.57
80	0.17	0.83	0.70	0.14	0.71	1.69	1.78	0.01	0.18	49	51	92.35

Table K-10 (Cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L
25	1	2	3	4	5	6	7	8	9	10	11	12
81	0.18	0.84	0.70	0.14	0.71	1.69	1.78	0.01	0.20	49	52	92.64
82	0.20	0.84	0.71	0.15	0.72	1.71	1.78	0.01	0.21	49	53	93.58
83	0.21	0.84	0.71	0.15	0.72	1.71	1.78	0.01	0.22	50	54	93.79
84	0.22	0.85	0.71	0.15	0.72	1.72	1.78	0.01	0.23	50	55	93.99
85	0.23	0.85	0.71	0.15	0.72	1.72	1.78	0.01	0.23	50	56	94.18
86	0.23	0.85	0.71	0.15	0.72	1.72	1.78	0.01	0.24	50	57	94.35
87	0.24	0.85	0.71	0.15	0.72	1.72	1.78	0.01	0.25	50	58	94.52
88	0.25	0.86	0.71	0.15	0.72	1.73	1.78	0.01	0.26	51	59	94.67
89	0.26	0.86	0.71	0.15	0.72	1.73	1.77	0.01	0.26	51	60	94.81
90	0.26	0.86	0.71	0.15	0.72	1.73	1.77	0.01	0.27	51	61	94.94
91	0.27	0.86	0.63	0.14	0.63	1.63	1.77	0.02	0.29	52	62	89.33
92	0.29	0.87	0.63	0.14	0.63	1.64	1.77	0.02	0.31	52	63	89.74
93	0.31	0.87	0.64	0.14	0.64	1.66	1.77	0.02	0.32	52	64	90.80
94	0.32	0.88	0.64	0.14	0.64	1.66	1.77	0.01	0.34	53	65	91.13
95	0.34	0.88	0.64	0.14	0.64	1.67	1.77	0.01	0.35	53	66	91.43
96	0.35	0.89	0.64	0.15	0.64	1.67	1.77	0.01	0.36	53	67	91.71
97	0.36	0.89	0.64	0.15	0.64	1.68	1.76	0.01	0.37	54	68	91.97
98	0.37	0.89	0.64	0.15	0.64	1.68	1.76	0.01	0.39	54	69	92.22
99	0.39	0.90	0.55	0.13	0.55	1.58	1.76	0.03	0.41	54	70	86.30
100	0.41	0.90	0.55	0.13	0.55	1.58	1.76	0.02	0.44	55	71	86.82
101	0.44	0.91	0.55	0.13	0.55	1.59	1.76	0.02	0.46	55	72	87.31
102	0.46	0.92	0.55	0.13	0.55	1.60	1.75	0.02	0.48	56	73	87.76
103	0.48	0.92	0.55	0.13	0.55	1.61	1.75	0.02	0.50	56	74	88.19
104	0.50	0.93	0.48	0.12	0.48	1.53	1.75	0.03	0.53	57	75	83.92
105	0.53	0.94	0.48	0.12	0.48	1.54	1.75	0.03	0.56	57	76	84.51
106	0.56	0.95	0.48	0.12	0.48	1.55	1.74	0.03	0.59	58	77	85.07
107	0.59	0.95	0.48	0.13	0.48	1.56	1.74	0.03	0.61	59	78	85.59
108	0.61	0.96	0.48	0.13	0.48	1.57	1.74	0.02	0.64	59	79	86.07
109	0.64	0.97	0.41	0.11	0.41	1.49	1.74	0.03	0.67	60	80	81.62
110	0.67	0.98	0.41	0.11	0.41	1.50	1.73	0.03	0.70	61	81	82.27
111	0.70	0.99	0.41	0.11	0.41	1.51	1.73	0.03	0.73	61	82	82.88
112	0.73	1.00	0.35	0.10	0.35	1.44	1.73	0.04	0.77	62	83	79.02
113	0.77	1.01	0.35	0.10	0.35	1.46	1.72	0.04	0.81	63	84	79.76
114	0.81	1.02	0.35	0.10	0.35	1.47	1.72	0.04	0.85	64	85	80.44
115	0.85	1.03	0.35	0.10	0.35	1.48	1.72	0.03	0.88	65	86	81.09
116	0.88	1.04	0.29	0.09	0.29	1.41	1.71	0.04	0.92	66	87	77.38
117	0.92	1.05	0.29	0.09	0.29	1.43	1.71	0.04	0.96	67	88	78.13
118	0.96	1.06	0.22	0.07	0.23	1.36	1.70	0.05	1.01	68	89	74.30
119	1.01	1.08	0.22	0.07	0.23	1.37	1.70	0.05	1.05	69	90	75.15
120	1.05	1.09	0.22	0.07	0.23	1.39	1.69	0.04	1.10	70	91	75.95
121	1.10	1.10	0.18	0.06	0.18	1.34	1.69	0.05	1.15	71	92	73.58
122	1.15	1.11	0.18	0.06	0.18	1.36	1.69	0.05	1.19	72	93	74.41
123	1.19	1.13	0.14	0.05	0.14	1.31	1.68	0.05	1.24	73	94	72.03
124	1.24	1.14	0.14	0.05	0.14	1.33	1.68	0.05	1.29	75	95	72.90
125	1.29	1.16	0.11	0.04	0.11	1.30	1.67	0.05	1.34	76	96	71.27
126	1.34	1.17	0.11	0.04	0.11	1.32	1.67	0.05	1.39	77	97	72.13
127	1.39	1.19	0.08	0.03	0.08	1.30	1.66	0.05	1.44	79	98	71.04
128	1.44	1.20	0.08	0.03	0.08	1.31	1.66	0.05	1.49	80	99	71.88
129	1.49	1.21	0.06	0.02	0.08	1.29	1.65	0.05	1.54	82	100	70.94
130	1.54	1.23	0.04	0.02	0.04	1.29	1.65	0.05	1.59	83	101	70.59
131	1.59	1.24	0.04	0.02	0.04	1.30	1.64	0.05	1.64	85	102	71.40
132	1.64	1.26	0.03	0.01	0.03	1.30	1.64	0.05	1.69	87	103	71.19
133	1.69	1.27	0.02	0.01	0.02	1.30	1.63	0.05	1.73	88	104	71.16
134	1.73	1.28	0.02	0.01	0.02	1.31	1.63	0.04	1.78	90	105	71.91
135	1.78	1.30	0.01	0.00	0.01	1.31	1.62	0.04	1.82	92	106	71.82
136	1.82	1.31	0.00	0.00	0.00	1.31	1.62	0.04	1.86	94	107	71.72
137	1.86	1.32	0.00	0.00	0.00	1.32	1.61	0.04	1.90	96	108	72.40
138	1.90	1.33	0.00	0.00	0.00	1.33	1.61	0.04	1.94	98	109	73.05
139	1.94	1.34	0.00	0.00	0.00	1.34	1.61	0.04	1.98	100	110	73.66
140	1.98	1.35	0.00	0.00	0.00	1.35	1.60	0.03	2.01	102	111	74.24
141	2.01	1.36	0.00	0.00	0.00	1.36	1.60	0.03	2.05	104	112	74.78
142	2.05	1.37	0.00	0.00	0.00	1.37	1.60	0.03	2.08	106	113	75.30
143	2.08	1.38	0.00	0.00	0.00	1.38	1.59	0.03	2.11	108	114	75.79
144	2.11	1.39	0.00	0.00	0.00	1.39	1.59	0.03	2.14	110	115	76.25
145	2.14	1.40	0.00	0.00	0.00	1.40	1.59	0.03	2.16	112	116	76.69
146	2.16	1.41	0.00	0.00	0.00	1.41	1.58	0.02	2.19	114	117	77.10
147	2.19	1.41	0.00	0.00	0.00	1.41	1.58	0.02	2.21	117	118	77.49
148	2.21	1.42	0.00	0.00	0.00	1.42	1.58	0.02	2.23	119	119	77.86
149	2.23	1.43	0.00	0.00	0.00	1.43	1.58	0.02	2.25	121	120	78.21
150	2.25	1.43	0.00	0.00	0.00	1.43	1.57	0.02	2.27	123	121	78.54
151	2.27	1.44	0.00	0.00	0.00	1.44	1.57	0.02	2.29	126	122	78.85
152	2.29	1.44	0.00	0.00	0.00	1.44	1.57	0.02	2.31	128	123	79.15
153	2.31	1.45	0.00	0.00	0.00	1.45	1.57	0.02	2.33	130	124	79.43
154	2.33	1.45	0.00	0.00	0.00	1.45	1.57	0.02	2.34	133	125	79.69
155	2.34	1.46	0.00	0.00	0.00	1.46	1.57	0.01	2.36	135	126	79.94
156	2.36	1.46	0.00	0.00	0.00	1.46	1.56	0.01	2.37	137	127	80.18
157	2.37	1.47	0.00	0.00	0.00	1.47	1.56	0.01	2.38	140	128	80.40
158	2.38	1.47	0.00	0.00	0.00	1.47	1.56	0.01	2.40	142	129	80.61
159	2.40	1.47	0.00	0.00	0.00	1.47	1.56	0.01	2.41	145	130	80.81
160	2.41	1.48	0.00	0.00	0.00	1.48	1.56	0.01	2.42	147	131	81.00